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FEUP FACULDADE DE ENGENHARIA
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SERIOUS GAMES
FOR HEALTH REHABILITATION

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TESE DE DOUTORAMENTO APRESENTADA
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Thesis submitted in partial fulfillment of the requirements for the degree of Doctor in Informatics Engineering of the University of Porto

Supervisor: Professor Doutor Luís Paulo Reis
Co-Supervisor: Professor Doutor Pedro Miguel Moreira

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Resumo

A área dos Jogos Sérios (tradução literal do termo *Serious Games*), e a investigação associada aos mesmos, têm tido nos últimos tempos um crescimento estimulado pelo uso cada vez mais disseminado de vídeo jogos e pelo aparecimento de novos recursos e metodologias para o seu desenvolvimento. Os Jogos Sérios têm aplicações importantes em áreas distintas, tais como as áreas: militar, saúde, governo e educação. A sua principal característica é serem usados para outros fins para além do entretenimento puro, normalmente associado ao conceito de jogo. O interesse por Jogos Sérios decorre do fato de que os jogos usam um conjunto de técnicas que os torna muito eficazes para envolver os utilizadores e manter sua motivação em níveis mais altos.

Com base nos pressupostos acima enunciados, o design de jogos de computador pode oferecer contribuições valiosas para desenvolver jogos efetivos na área da reabilitação em Saúde. Nos programas de reabilitação, um dos principais problemas relatados está relacionado com a motivação e envolvimento dos pacientes nas sessões de exercícios usando as abordagens tradicionais. Os pacientes rapidamente perdem o interesse e ficam menos motivados para realizar as tarefas, geralmente repetitivas, de reabilitação.

A presente tese aborda os Jogos Sérios para a Reabilitação em Saúde (*Serious Games for Health Rehabilitation - SGHR*), e fornece um estudo e levantamento aprofundado dos jogos e recursos existentes nesta área. Com este estudo, fomos capazes de elaborar e propor uma taxonomia que permita aos investigadores e profissionais usar uma abordagem sistemática para estudar, classificar e comparar os jogos. Esta taxonomia foi validada por um conjunto de especialistas nos domínios do conhecimento relacionados com o projeto, desenvolvimento e utilização de Jogos Sérios para Reabilitação em Saúde. A investigação aqui descrita permitiu também identificar e propor várias características importantes, bem como diretrizes, a serem incluídas no desenvolvimento de Jogos Sérios para Reabilitação em Saúde. Como um dos resultados mais importantes, propomos, discutimos e descrevemos uma plataforma para o desenvolvimento de jogos sérios. Esta proposta integra um conjunto de características de interação natural e multimodal, interação social (colaboração e competição) e monitorização

de progresso, que podem ser utilizados para aumentar a motivação dos pacientes durante o processo de reabilitação.

Para validar a proposta, foi desenvolvido um conjunto de jogos sérios. Esses jogos são destinados a ser usados em sessões de reabilitação, e seu principal objetivo é aumentar a motivação dos utilizadores durante o processo de reabilitação. Os jogos desenvolvidos tiveram por base sistemas e tarefas de reabilitação bem estabelecidos na comunidade de profissionais de reabilitação. Descrevemos o design e a implementação dos jogos com referência à nossa proposta de *framework*. A plataforma de jogos apresentada inclui um conjunto de características, como mecanismos de competição, colaboração e *handicap*, com o objetivo de promover o envolvimento e a motivação dos pacientes durante o processo de reabilitação. O sistema resultante é uma plataforma Web que permite que os jogos sejam jogados *online*, tornando-a mais acessível para todos os utilizadores, incluindo pacientes em reabilitação. Além disso, a plataforma Web oferece uma solução de baixo custo para a reabilitação dos pacientes e facilita a reabilitação no domicílio, para além da terapia tradicional em clínica.

As experiências finais foram realizadas para validar a proposta de framework e fornecer evidências de que é possível usar Jogos Sérios para Reabilitação em Saúde, em particular para aumentar os níveis de motivação dos utilizadores destes jogos. As experiências foram realizadas com pessoas saudáveis e utilizadores idosos. Os resultados alcançados em todos os testes foram bastante bons, com ênfase para os muito bons resultados associados à usabilidade e motivação (*SUS* e *IMI*).

Abstract

Serious Games are growing into a significant area spurred by the growth in the use of video games and of new methods for their development. They have important applications in several distinct areas such as: military, health, government, and education. As such, their purpose is to be used for other purposes than pure entertainment, which is normally associated with the concept of game. The interest for Serious Games arises from the fact that games have a set of features that makes them very effective to engage users and keep their motivation at higher levels.

From the above discussion, the design of computer games can offer valuable contributions to develop effective games in the rehabilitation area. In rehabilitation programs, one of the major problems reported are related to the motivation and engagement of patients in the exercises training sessions using traditional therapy approaches. Patients rapidly lose their interest and get bored doing the, usually repetitive, rehabilitation tasks.

This thesis addresses Serious Games for Health Rehabilitation (SGHR), and provides an in-depth study and survey of the existent games and features. With this study we were able to devise a taxonomy that enables researchers and practitioners to use a systematic approach to study, classify and compare SGHR. This taxonomy is validated by a set of experts in the interrelated domain of knowledge. The research led us to identify and propose several important features and guidelines to include in SGHR. As a result, we propose, discuss and describe a framework for the development of serious games. The framework integrates a set of features of natural and multimodal interaction, social interaction (collaboration and competitiveness) and progress monitoring, which can be used to increase the motivation of the patients during the rehabilitation process.

To validate the proposed framework and features, a set of serious games were developed. These games are intended to be used in rehabilitation sessions, and their main goal is to increase the users' motivation during the rehabilitation process. The developed games were designed based on well established rehabilitation systems and rehabilitation tasks. We describe the design and implementation of the games with respect to our proposed framework. The resulting game platform includes a set of features, such as competitiveness, collaboration and handicap mechanisms, with the aim of promoting the engagement and motivation of the patients involved in the rehabilitation process. The resulting system is a Web platform that enables games to be played online, making it more accessible to all users, including patients in rehabilitation. Besides that, the web platform provides a low cost solution to patients training and enables home rehabilitation, in addition to traditional therapy.

Final experiments were performed in order to validate the proposed framework and provide scientific evidence that it is possible to use serious games for health rehabilitation to increase the motivation of users. Experiments were conducted with healthy people and elderly users. The scores achieved in all the tests used were quite good with emphasis for the very good SUS and IMI scores achieved.

“Knowing is not enough; we must apply.
Willing is not enough; we must do.”
—Goethe

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Paula A. Rego

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Chapter 1

Introduction

Serious games are growing into a significant research area spurred by the advances in game development and in computer graphics hardware, in turn driven by the success of video games. Nowadays this concept is largely used in respect to computer games, although Serious Games may not be restricted to computer based games. For the purpose of this thesis we will use the term Serious Games to refer to the subset of computer serious games. They are becoming so popular that we are witnessing the rising of new audiences of players that were not usual consumers of the most traditional games. An example of this can be seen by the popularity obtained by the Nintendo Wii system [1], the Microsoft Kinect system [2] or the Sony PlayStation Move System [3], which are being played by people of all ages and/or entire families and not only by the most “hard-core” players. This interest for games and their dissemination can be exploited for other purposes than mere entertainment.

This work focus on the use of Serious Games for Health Rehabilitation (SGHR) with emphasis on the use of web based games with social features, including competition and collaboration for cognitive rehabilitation. In this chapter we will present the main motivation and the main goals of this thesis.

1.1 Motivation

The field of Serious Games is an active and multidisciplinary research topic focused on using games with other purposes than mere entertainment. The motivation to use computer games in such contexts is manifold. In one hand, computer games are becoming an important and disseminated cultural product. At the other hand, games are activities designed to be enjoyable and keep the players’ attention and motivation. Thus, designing games with other objectives than pure entertainment can lead to increased efficiency of the underlying process.

The main motivation of this work is to give a contribution to reduce one of the major problems occurring in the rehabilitation of elderly people and patients suffering from some kind of cognitive disability, which is related to the motivation needed in the rehabilitation sessions to perform the prescribed exercises. High social costs result in a major part from high costs in the rehabilitation of a variety of disabilities resulting from diseases or traumatic incidents. It has been shown that most of these patients sometimes get into depression [4] as soon as the rehabilitation programs begin, which increases even more the associated healthcare costs. The problem is that traditional treatment approaches include exercises often considered repetitive and boring for patients and so an "extra" motivation is required to keep these patients continue practicing the rehabilitation exercises. A continued practice of rehabilitation tasks will give these patients more opportunities to recover more rapidly from their disability condition and to return to their normal life. At same time they are doing the exercises, they could enjoy and have fun and this would contribute to diminish their pain or to distract from their disability state.

One solution to offer patients the motivation referred is the use of computer games in the therapy sessions. Games require cognitive and motor activity so they can engage a person's attention [5]. Games have a story, a set of challenges and they motivate the patient to accomplish the defined goals, by the use of tasks that were designed for rehabilitation. Besides enabling to accomplish the final "top-level" goal that is rehabilitation, the game offers the patient the possibility of being immersed in a different situation where he tries to accomplish the goals proposed in the game. Playing the game can distract the patient from his disability condition and from the fact that he is in a rehabilitation activity. Besides, most games can offer difficult levels that give the patient a sense of challenge in his progress and in a way that can also be adapted to his skills. In this sense, apart the serious goal of the patient recovery, the game gives also to the patient: immersion, challenge, motivation, enjoyment, sensations that he could not feel if he was only repeating a sequence of tasks that were part of his rehabilitation plan.

Additionally, there are some aspects that can favor the use of computer games in rehabilitation therapy sessions. Games are becoming more accessible to people in general. Computer systems are becoming more disseminated and affordable to users in general, in the form of several devices: game consoles, portable personal computers, large display TV sets, mobile devices, etc. At the same time, people tend to have more literacy about information systems and computer technologies, and this promotes the accessibility to computer games.

On the other hand, we are witnessing the rising and development of more natural user interfaces that are changing the traditional interaction paradigm of mouse and keyboard to other new forms of input: gestures, force feedback, balance feedback, facial expression recognition, and voice recognition, to name some of the more relevant modalities of input. These new forms of interaction can be used to create applications that tend to be more natural and free, as they foster the elimination of artificial input devices in the human-computer interaction. These new forms of interaction can be used in order to increase the quality and efficiency of the rehabilitation process.

Another important aspect that can favor SGHR is the fact that people are connected to the internet using more bandwidth, which enables network rehabilitation games and the fulfilling of rehabilitation plans at home, in many cases without having to move the patient to the clinic/hospital. The rehabilitation plans can be adjusted in some cases by the therapist, remotely, which contributes to a greater comfort, time economy and autonomy development to the patient. Additionally, as patients can be connected by the web, this promotes the introduction of social components in the games, which can be used in the creation of new scenarios of rehabilitation where patients can cooperate and compete at a distance.

Another very important aspect is that games distract the patient's attention and as such they can be used to aid in the management of pain [5, 6].

1.2 Objectives

Traditional rehabilitation approaches include exercises often considered repetitive and boring for patients [6]. Using computer games, the motivation and engagement can increase, due to the cognitive and motor activity required by the game. Serious games can thus offer the potential for a significant therapeutic benefit [5]. However, designing a game with all the features that could benefit the outcome of patient's rehabilitation is a complex task. Design methodologies, narrative structure, visual arts, interaction techniques and modalities and technologies commonly available in computer games are many of the factors that could influence the results.

We believe that the design of computer games can offer valuable contributions about how to develop more effective games for rehabilitation programs. In that sense, one of the fundamental goals of our research is to identify, classify and assess game features that are relevant for the design of computer games in this area. Therefore, this work intends to identify and evaluate the impact of a set of game features in SGHR that could be relevant for a more effective rehabilitation process. As a main contribution we intend to propose a modular architecture for the development of SGHR comprising the identified features.

This comprehensive goal can be decomposed in the following objectives:

- To identify the game features that can contribute to a better rehabilitation regarding to the existing approaches;
- To define a taxonomy for serious games for health rehabilitation and perform an initial validation of the taxonomy with a set of experts;
- To define a framework that takes into account the game features and requirements identified enabling the development of SGHR.

- To design and implement a small set of games that follow the chosen set of features in the context of the framework developed;
- To test the games implemented with a sample of users, validating and evaluating the approach.

The proposals are intended to be validated in realistic scenarios with healthy users and a subset of users with cognitive impairments.

1.3 Thesis Statement

It is our intention, in our research work, to determine the benefits of the adoption of serious games in respect to rehabilitation programs. Based on the state of the art and in the identified limitations of the reviewed works (chapter 2) we found as important research opportunities the exploitation of features such as collaboration, competition and new forms of interaction that could be more "natural" and more easily deployed and accessible to the patients.

So, the main goal of our thesis is to propose a framework for the development of serious games that integrates a set of features such as social skills (collaboration and competitiveness) and progress monitoring which can be used to increase the motivation of patients in rehabilitation.

In order to validate this proposal, a set of serious games will be developed that can be used in rehabilitation sessions to increase the motivation of the patients during that process.

Based on the previous, we state our research hypothesis as: "Serious games designed with social dimensions, as collaboration and competition, increase the motivation and engagement of patients in cognitive rehabilitation".

An increased effectiveness of the rehabilitation process is expected, in respect to current approaches, driven by a higher level of playability and from improved motivational factors because of the incorporation of social components in the games. A proof-of-concept serious game system will be implemented in order to demonstrate and quantify our proposed framework.

1.4 Contributions

Addressing our research question, this thesis adds the following contributions to the current state-of-the-art:

- We conducted a systematic review of the literature concerning games for health rehabilitation and identify current trends;
- We proposed a taxonomy for health rehabilitation games that is now widely used in the community;
- We extended and validated the taxonomy proposal using experts in the area;

- We proposed a new framework for the development of serious games in health rehabilitation;
- We designed and developed a set of web-based games containing social features, which may be used for rehabilitation using our framework;

We analyzed the games usability and the users' engagement and motivation in playing the games showing that social features increase patients' motivation and engagement.

Besides these contributions, the work presented in this thesis also allowed the project divulgation through international scientific publications.

1.5 Publications

Some parts of the work herein presented have been published in the following publications:

- P. Rego, P. M. Moreira, L. P. Reis, "Serious Games for Rehabilitation: A Survey and a Classification Towards a Taxonomy", In Proceedings of the 5th Iberian Conference on Information Systems and Technologies, 16-19 June, Santiago de Compostela, Spain, vol. I, pp. 349—354, 2010.[SCOPUS][ISI][IEEExplore] (230 citations at Google Scholar) (132 citations at SCOPUS)
- P. Rego, P. M. Moreira, L. P. Reis, "A Survey on Serious Games for Rehabilitation". In: A.A. Sousa and E. Oliveira, ed., Proceedings of the 5th DSIE'10 Doctoral Symposium in Informatics Engineering, 28-29 January, FEUP, Porto, pp. 267-278, 2010.
- P. A. Rego, P. M. Moreira, and L. P. Reis, "Natural User Interfaces in Serious Games for Rehabilitation: a Prototype and Playability Study," First Iberian Workshop on Serious Games and Meaningful Play (SGaMePlay'2011) in Proceedings of the 6th Iberian Conference on Information Systems and Technologies, AISTI, 15-18 June, Chaves, Portugal, vol. II, pp. 229-232, 2011. [SCOPUS][ISI][IEEExplore]
- P. A. Rego, P. M. Moreira, and L. P. Reis, "New Forms of Interaction in Serious Games for Rehabilitation," in Handbook of Research on Serious Games as Educational, Business, and Research Tools: Development and Design, M. M. Cruz-Cunha, Ed., ed: IGI Global, 2012. [SCOPUS]
- P. A. Rego, P. M. Moreira and L. P. Reis, "Architecture for Serious Games in Health Rehabilitation", Álvaro Rocha, Ana Maria Correia, Felix B. Tan, Karl A. Stroetmann. New Perspectives in Information Systems and Technologies, Volume 2. ed.: Springer International Publishing, 2014, v. 276, p. 307-317 [SCOPUS][ISI][Springer]
- P. A. Rego, P. M. Moreira, L. P. Reis, "Natural and Multimodal User Interfaces in Serious Games for Health Rehabilitation" in: MASH'14: Multi-Agent Systems for Healthcare / AAMAS'14 - 13th International Conference on Autonomous Agents and Multiagent Systems, IFAMAAS, Paris, France, 2014

- P. A. Rego, P. M. Moreira, L. P. Reis, “A Serious Games Framework for Health Rehabilitation” in International Journal of Healthcare Information Systems and Informatics (IJHISI), vol. 9, pp. 1-21, 2014 [SCOPUS] [ISI]
- P. A. Rego, P. M. Moreira, and L. P. Reis, "A Serious Games Framework for Health Rehabilitation," in Gamification: Concepts, Methodologies, Tools, and Applications, I. R. M. Association, Ed., ed Hershey, PA, USA: IGI Global, 2015, pp. 404-424 [SCOPUS]
- R. Rocha, L. P. Reis, P. A. Rego, and P. M. Moreira, "Serious games for cognitive rehabilitation: Forms of interaction and social dimension," in 2015 10th Iberian Conference on Information Systems and Technologies (CISTI), 2015, pp. 1-6. [SCOPUS][ISI][IEEExplore]
- R. Rocha, L. P. Reis, P. A. Rego, P. M. Moreira, and B. M. Faria, "New forms of interaction in serious games for cognitive rehabilitation: Implementation and usability study," in 2016 11th Iberian Conference on Information Systems and Technologies (CISTI), 2016, pp. 1-6. [SCOPUS][ISI][IEEExplore]
- R. Rocha, P. A. Rego, B. M. Faria, L. P. Reis, and P. M. Moreira, "A Web Platform of Serious Games for Cognitive Rehabilitation: Architecture and Usability Study," in New Advances in Information Systems and Technologies. vol. 1, Á. Rocha, et al., Eds., ed: Springer International Publishing, 2016, pp. 1085-1095. [SCOPUS][ISI][Springer]
- P. A. Rego, P. M. Moreira, and L. P. Reis, "Jogos Sérios na Reabilitação Cognitiva e Motora," in Poster presented at Ciência 2016 - Encontro com a Ciência e Tecnologia em Portugal, ed. Centro de Congressos de Lisboa, 2016.
- P. A. Rego, R. Rocha, B. M. Faria, L. P. Reis, and P. M. Moreira, "A Serious Games Platform for Cognitive Rehabilitation with Preliminary Evaluation," Journal of Medical Systems, vol. 41, p. 10, 2017. [SCOPUS][ISI][Springer] (IF: 2.21)

1.6 Structure of the Document

This thesis is organized in eight main sections, corresponding to an equal number of chapters. The first one is the current introduction, where we have introduced the problem, the motivation of the research, our thesis statement, the main objectives to accomplish and the work contributions and publications.

Following, the next chapter is composed of three main sections. The first section presents an introduction to Serious Games including definitions, main goals, classifications and main application areas. The second section describes the role of simulation in Serious Games, presenting relevant works in the health and rehabilitation application field. In the third section we make a revision of the main literature on serious games for rehabilitation. This presentation is biased towards the use of serious games in the context of rehabilitation tasks.

The third chapter presents a revision of the main interaction technologies associated with natural user interfaces, with references to its application on rehabilitation processes. It presents the major input modalities associated to the use of natural user interfaces with a description focused in the technology main goals, main applications and finally its application in the rehabilitation domain.

The fourth chapter presents the taxonomy initially proposed for Serious Games in Health Rehabilitation (SGHR). Next, a comparison of the reviewed games according to the proposed criteria is provided. Following the classification of reviewed Serious Games, a study of the input modalities present in the reviewed rehabilitation serious games was done, providing thus a classification of Serious Games focused on the use of NUI. As several authors have been adopting our taxonomy in the design of their rehabilitation serious game prototypes, we update our state of art in this area presenting a description of the context of their work and the criteria they adopt to describe their games. Some of these authors extended our taxonomy including some more relevant criteria. Next, an update to our first proposal is done and an extended taxonomy for Serious Games in Health Rehabilitation is proposed. Additionally, in order to validate the interest and applicability of the proposed extended taxonomy a survey was done among experts in the area and in related areas and is presented, along with their results. As some of the participants made proposals concerning modifications to our extended taxonomy, an improved proposal for the extended taxonomy is presented.

Chapter 5 describes the proposal for a SGHR Framework Architecture its reference system, requirements for interaction, social features, feedback, accessibility, usability, validation, and the main modules that compose the framework.

The sixth chapter presents the main implementation details concerning the games developed throughout this project in order to study and test the thesis statement.

Chapter 7 is concerned with the experiments and results and describes a preliminary study with a motion detection prototype, the Rehab+– usability study with healthy users and a simple usability study with elderly users.

The last chapter describes the main conclusions, the contributions of this research and possible future work.

Chapter 2

Serious Games for Rehabilitation

Most studies on rehabilitation of users with some disability or impairment show that an effective rehabilitation must be early, intensive [7] and repetitive [6, 8, 9]. However it is difficult to maintain user motivation and interest during the rehabilitation tasks [6, 9, 10]. As a consequence, the game design with rehabilitation purposes is usually a complex task. In this chapter, a comprehensive review of the main literature concerning these problems is presented. The chapter starts by presenting a concise introduction on Serious Games, including fundamental terminology and concepts, classifications and examples of application. Following, the importance of the use of simulation in Serious Games is presented along with relevant examples of applications which comprise simulations, at different levels, in the health and rehabilitation domain of application. A review of the most relevant literature on SGHR is presented. Additionally, as a main result of this work, research opportunities and open problems in this field of research are identified. Finally, main conclusions derived from the literature review made on SGHR are highlighted.

2.1 Serious Games

Serious Games is an emergent field of research with applications in many diversified areas that focuses in the use of games with other purposes than mere entertainment. As the success and proliferation of video games grows, the later have the potential to be more than just entertainment, just like books, movies and television. According to Michael & Chen [11], the time has come for video games to become more relevant, more responsible, and more important or, in other words, to get serious. Consequently, the research community and the game industry moved towards the development of more elaborate games, incorporating both pedagogical and entertaining elements.

The amount of research in this field has grown significantly during the past two decades. All around the world a growing number of seminars and conferences are organized. In 2002, was formed the Serious Games Initiative [12] that helps the area of Serious Games emerge into an organized industry of developers aiming to solve distinct problems and informs us about the potential of games and how to merge innovation and developers from multiple disciplines that help in the growing of the Serious Games research field. In 2009 it was organized the first conference specialized in serious games: VS-GAMES'09 – First IEEE International Conference in Games and Virtual Worlds for Serious Applications, in the World's premier Serious Games Institute in UK.

The term serious game is becoming more and more popular, but there is no current single definition of the concept. Zyda [13] defines a serious game as: "a mental contest, played with a computer in accordance with specific rules, which uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives." For this author the pedagogic component of serious games is the one that makes them serious, not just the story, art and software elements that compose them. Although the entertainment component is the first one to arise, the pedagogic component subordinated to the story of the game gives the education or instruction that will enable the knowledge and skills that characterize serious games applications.

Michael and Chen [11] define serious games as "games that do not have entertainment, enjoyment or fun as their primary purpose". Although there are many definitions of the term, it is agreed by the different authors that the term refers to the use of games that have a main purpose that is not pure entertainment. In fact, Serious Games have been applied in many diverse areas: corporate and military training [14], health [15-17], education [18-23], cultural training [15, 21, 24-27]. Many of these areas are related and sometimes overlapped, like e-learning, edutainment, game-based learning and digital game-based learning. A notorious example of such overlapping is games classified under the concept of edutainment. Edutainment, or education through entertainment, is not limited to video games, as it refers to any form of education that also seeks to entertain [28]. Serious games refer to games, and thus to their entertainment nature, but are not restricted to educational purposes. Therefore, all previous applications are comprehended in the broader concept of Serious Games.

Serious games can be of any genre, use any game technology, and be developed for any platform. They can be entertaining, but usually they teach the user something or permit him to develop skills. In our work we define Serious Games as computer games that allow the player to achieve a specific purpose using the entertainment and engagement component provided by the experience of the game.

Serious games can also be classified in a number of different ways. Zyda [13] states that Serious Games technology can be applied to domains as diverse as healthcare, public policy, strategic communication, defense, training, and education. Michael and Chen [11] classify

Serious Games into a number of markets: military games, government games, educational games, corporate games, healthcare games, and political, religious and art games. Susi et al. give an overview of Serious Games [29]. Despite such classifications, many games could belong to more than one category. Sawyer and Smith [30] introduced in 2008 a Serious Games taxonomy to serve as a starting point to define serious games and invited the research community to contribute to a next version of their classification.

As referred before, the spectrum of Serious Games application areas is broad. For example, the military area has a long history of using games for training. An example of a Serious Game for training in this area is “Army Battlezone”, designed in 1980 by Atari [31]. However, “America’s Army” [32] was one of the most well-known, released in 2002 [29]. Examples of serious games application can be found in several other diverse areas as referred before.

A Serious Game has a specific goal that goes beyond pure entertainment. It aims to create simulations and user experiences that can be used to attain a specific goal. By taking advantage of game technology in order to create more attractive user experiences and increasing playability, the environments and tasks simulated in the serious game can be used to teach or train users in various situations. The same strategy can also be used with other purposes as for the individual growth and development, phobia therapy, advertisement, and marketing, to name some relevant applications. In many of these applications the use of simulated models becomes convenient or necessary in order to represent in an accurate way several aspects of the game, as it is the case of other players and their behavior, the surrounding environment, and cognitive or motor processes.

Simulation is a fundamental process in computer games. Next, the relevance of simulation in the context of Serious Games is described. The following discussion is focused in the health and rehabilitation application field and presents relevant work reported in the literature.

2.2 Simulations and Serious Games

Simulation is the imitation of some real thing, state of affairs, or process, over time, seeking to represent certain key characteristics or behaviors of the selected physical or abstract system.

As systems are getting more complex and more dynamic, simulation can be used in many domains as a way to understand and integrate their complexity and changeability. It is used in many contexts which vary from decision making, to the modelling of natural systems or human systems in order to gain insight into their functioning or the simulation of technology for performance optimization, safety engineering, testing, training and education [33, 34].

A simulation models a process (or mechanism) determined by a specific algorithm and enables users to solve problems and make decisions by laying emphasis in the relation of interacting and varying inputs to the targeted outcomes [35].

Although there are no widely accepted distinctions between games and simulations, Table 1 presents some rough distinctions between computer simulations and computer games, presented by Tobias and Fletcher in 2011 [34].

Table 1 - Comparison of simulations and games, according to Tobias and Fletcher [35]

Simulations	Games
Will sacrifice entertainment in favour of reality	Will sacrifice reality in favour of entertainment
Scenario/Tasks	Storyline/quest
Emphasis on task completion	Emphasis on competition
Not necessarily interactive	Necessarily interactive
Focus on (rule) accuracy/detailed	Focus on (rule) clarity/stylised
Not all simulations are games	All games are simulations

According to Tobias and Fletcher all games are simulations (even abstract games such as Tetris), but games also differ from simulations in some aspects that we can use to distinguish them. According to them, simulations differ from games in terms of how they are used: simulations emphasize the task completion and rule accuracy, and games focus on competition and rule clarity.

For Johnston and Whitehead (2009, in [36]), games are used for fun, while Serious Games and training simulations are used with an academic goal in mind. As Table 1 shows, games are usually thought of as having lower degrees of realism than simulations. For Johnston and Whitehead (2009), a difference between training simulations and Serious Games is their distance to the user's reality: simulations have a sense of closeness to reality that Serious Games do not have.

A game can apply simulation technology, but it has other elements that transform it into a game, such as scores, narrative elements, or elements of competition [37].

According to Taylor [35], while the game does not necessarily resemble the real world in a physical sense (mainly due to the high development costs involved), it evokes a sense of believability on a psychological level, such as engagement, stress, and communication. Based on that it can be said that games give higher priority to a psychological cognitive fidelity, while most training simulations give higher priority to a higher realism in terms of physical fidelity. The fidelity of the simulation (or simulation realism) refers, in this context, to the degree of similarity between the training situation and the operational situation that is simulated (Hays & Singer,1989 in [36]). Taylor categorizes fidelity into physical, functional, task, and psychological fidelity. Physical fidelity refers to the degree to which the simulation looks and feels like the real world, whereas Psychological-cognitive fidelity refers to the degree to which psychological, emotional, and cognitive aspects are represented in the simulation. The author states that physical fidelity has lower priority in most serious games also due to the fact that it has little impact on what is thought to make a game ‘fun.’ In many situations, the fact of having increasingly realistic graphics may not affect enjoyment. For example, too much realism can make a game too challenging for an average player, and might give unrealistic expectations about what can be done within the game world [38].

Simulations can be used in many domains with diverse goals. They are typically used to manage system complexity. In health domain, simulation can be used at different levels: environment, patient, therapist or all (environment and users of the environment).

The simulation of the environment can be achieved by placing the user (patient) in a more controlled environment and measuring his progress over time, adjusting practice sessions to patient needs or impairments. In a controlled environment, close to the real world, the user progress can be measured, facilitating experiments and predictions and creating a risk free and/or cost effective solution. In many applications, Virtual Reality (VR) is used to provide immersion. Noticeable examples of these applications are presented in [39], that describes the use of a driving simulator, in [40] describing the use of an electric wheelchair simulator, in [41] describing a VR Bicycle Simulator, and in [42] that describes a computer assisted rehabilitation environment system for civilian and military patient recovery.

The simulation of the patient can be seen by the use of a physical representation of the patient body or of a part of the patient’s body. The former consists in an artificial patient that is a computer connected to a life size mannequin which mimics body functions (heartbeat, respiration, replicate symptoms of illness) and that can be programmed to recreate life-threatening emergency situations and to respond to injected drugs [43, 44]. This has the advantages of teaching trainees’ technical abilities, and establishing pre-clinical proficiency by allowing unlimited and consequence-free practice, transfer of skills learned in the simulated environment into the real-world clinical environment, and by providing motivation to learning by giving feedback from decisions and actions. An example of the later is given by Hageman [45] that describes the use of a hand model as a training tool to make orthoses. In other simulations, visual and virtual representations of medical processes are reproduced using computer graphics techniques, haptic feedback devices, and physical simulation. Examples of these applications are described in [46] and seen from the virtual laparoscopic simulator [47] of the University of Mississippi Medical Center which describes suturing tasks and the simulated cholecystectomy procedure. Another example describes surgical simulations such as a cataract surgery simulation [48].

The simulation of the therapist can be seen in systems that minimize the presence of the therapist in the rehabilitation session. Examples of these applications include mainly the use of robotic systems that assist the patient in the rehabilitation session and help to reduce dependency from the therapist [49, 50].

On the other hand, the environment and users’ simulation is used to simulate an envisioned facility to allow the planning, predicting and improvement of operation and procedures.

Examples of applications included in this category can be seen in [51] that describes a medical simulation in the virtual world of Second Life platform, used in nursing courses, which represents virtually the environment of an envisioned clinic, the virtual patient, the virtual therapist and the clinic functioning and procedures. Another example can be seen in [52] which describes a serious game demo application that can be used to train medical first responders, representing virtually the patient, the room and the procedures the therapist has to do.

Simulation may play a very important role in Serious Games for Rehabilitation as it is can be used to simulate the environment and the tasks the patient has to do in a rehabilitation session. In the rehabilitation area, it has been used to simulate the system environment and mostly the therapist: by means of a computer game, the rehabilitation training exercise is simulated for the patient, minimizing the presence of the therapist. In this section, the relevance of simulation and as well as its interrelation with games were discussed.

2.3 Serious Games for Health Rehabilitation (SGHR)

A major application of Serious Games is in the rehabilitation area which is the main focus of the current research.

Rehabilitation is defined in [53] as a dynamic process of planned adaptive change in lifestyle in response to unplanned changes imposed on the individual by disease or traumatic incident.

The World Health Organization (WHO) defines Rehabilitation as: “an active process by which those affected by injury or disease achieve a full recovery or, if a full recovery is not possible, realize their optimal physical, mental and social potential and are integrated into their most appropriate environment”. The Rehabilitation goal is that people who have a disability or are at risk of disability may achieve optimal functioning, autonomy and self-determination when interacting with the larger physical, social and economic environment [54].

The success of a rehabilitation program depends on various factors: appropriate timing, patient selection, choice of rehabilitation program, continued medical management and appropriate discharge planning. This can be achieved in a multidisciplinary way (medical, nursery, social personnel) and with an appropriately equipped rehabilitation department where adequate therapy treatments (physical therapy, occupational therapy, speech and language therapy, clinical psychology and social work) are combined in a planned and coordinated way towards a common goal [53].

According to WHO [55], around the world, around 15 million strokes occur each year, leaving 1/3 of survivors with cognitive and / or motor abnormalities. In addition to motor deficits, in 70% of cases stroke is responsible for cognitive deficits affecting the ability to independently and safely perform daily life activities (ADLs) [56].

2.3.1 Cognitive and Motor Rehabilitation

Cognition refers to the mental processes that are involved in acquiring knowledge and comprehension, that is the capabilities or intellectual skills that make us think, perceive things, acquire, understand, and respond to information. These include the abilities to: pay attention, remember, work information, solve problems, organize and reorganize information, communicate and to act upon information. All of these capabilities work in their own and connect with one another to allow us to function in our environment [57]. Cognitive deficits are a common expression of highly prevalent neurological and psychiatric conditions that may affect individuals of all ages. Neurological disorders are diseases that affect the brain and the central and autonomic nervous systems. There are many types of neurological disorders, including: Alzheimer's disease (AD), Multiple sclerosis, Parkinson's disease, epilepsy, etc. Cognitive training plays an important role in the treatment of patients with cognitive deficits.

According to the definition used by the Brain Injury Interdisciplinary Special Interest Group (BI-ISIG) [58], "*Cognitive rehabilitation is a systematic, functionally oriented service of therapeutic cognitive activities, based on an assessment and understanding of the person's brain-behavior deficits. Services are directed to achieve functional changes by (1) reinforcing, strengthening, or reestablishing previously learned patterns of behavior; or (2) establishing new patterns of cognitive activity or compensatory mechanisms for impaired neurological systems* (Harley et al., 1992)" [59].

The main objective of cognitive rehabilitation is the improvement of cognitive skills affected as a result of suffered brain damage. In this sense, it focuses mainly on returning patients to the maximum possible independence and the best possible functioning of their cognitive functions. These processes include cognitive faculties such as attention, concentration, memory, reasoning, problem solving, and language, among others.

Cognitive dysfunction can be treated in three ways: using remediation techniques, using compensatory strategies, or using adaptive approaches. Most experts consider that a cognitive rehabilitation program uses techniques from different approaches. [57]

The Institute of Medicine (IOM) [59] describes two broad approaches to Cognitive Rehabilitation Therapy:

- Restorative (or remedial) treatment, whose goal is to improve the cognitive system to function in a wide range of activities, restoring the cognitive functions impaired by the stroke;
- Compensatory treatment, which trains solutions to specific problem areas such as using memory notebooks or learning self-cuing strategies.

Patients in rehabilitation may have suffered from different disabilities or disorders such as Stroke and Traumatic Brain injury. The WHO provided definitions and differences between the concepts of Impairment, Disability, and Handicap in the International Classification of Impairments, Disabilities and Handicaps [60] as follows:

- Impairment: Any loss or abnormality of psychological, physiological or anatomical structure or function.
- Disability: Any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human being.
- Handicap: A disadvantage for a given individual, resulting from an impairment or disability, that limits or prevents the fulfilment of a role that is normal, depending on age, sex, social and cultural factors, for that individual.

Stroke (also known as cerebral vascular accident - CVA) has been referred in literature as the major cause of the long term disabilities among adults in industrialized nations [61] (WHO, 2017). A stroke usually occurs when a blood clot stops the flow of blood to a portion of the brain. After a few minutes, the cells of the brain that are lacking the blood begin to die and patients who survive a stroke can suffer cognitive, visual and motor losses. In terms of cognitive functions, stroke survivors may have losses in memory and speech that can affect highly his interaction with the world [62]. Some of the patients experience unilateral neglect as a result of stroke in which they lack the perception in one side of their visual side. It is also common in these patients to occur motor problems like paralysis or weakness on one side of their bodies. Activities of daily life like feeding, dressing and bathing can be limited in these patients when they lose the ability to use their arm. All these problems make difficult for the patients to get back to their normal life.

The use of the affected members of the body has to be encouraged through exercise so the patient can relearn the ability to use them again. This process is usually very slow and demanding and may require hundreds of repeated movements every day. Typically, patients participate in therapy programs under the supervision of a therapist. These programs show that the primary concern in early inpatient stroke therapy is on the lower extremity (i.e., legs), to promote the patients' mobility. The recovery of the upper extremity (i.e. arms) has a slower progression and is usually acquired with outpatient and home therapy. Typically, the recovery of the upper extremity starts from these patients getting mobility from their shoulder, and then they gradually may regain motion in the elbow, wrist, and finally, the hand. However, due to limitations on therapy much of the work necessary for the arm recovery must be done at home. The existence of home-based technologies that can motivate the patients to continue practicing the exercises out of rehabilitation clinic assumes therefore a very important role.

In fact, major tests reported from rehabilitation programs of patients with impairments and disabilities show that patients' function improves with an intensive training that is oriented in the achievement of a goal and is divided in specific tasks [6, 63]. The main problem with this task-specific treatment approaches, however, is the lack of patient interest in performing repetitive tasks and in ensuring that they finish the treatment program [6].

On the other hand, it has been shown that games contribute to increase motivation in rehabilitation sessions. Various research projects have been studying how to use games to help patients recovering from impairments or disabilities.

The application of VR technology for the rehabilitation of cognitive and motor deficits has been growing in the last decade and stroke patients have been one of the main target populations for these new rehabilitation methods [6]. These VR based-methods can offer the patients to be part of immersive experiences that are engaging and rewarding for them, which is the key to recovery.

Several similar works have been reported in the literature that identified important game characteristics in the rehabilitation area. Jung et al. [64] consider important the human factors: identification of target audience, visibility and feedback. Goude et al. [65] identified different game elements to address the most typical problems among stroke patients and developed and tested a number of games with these elements. Flores et al. [66] expanded the work of Goude et al. [65] by proposing a classification of games for elderly rehabilitation that could serve as a general indicator for the appropriateness or adaptability of each game in that area. They identified game design criteria that derive from stroke rehabilitation and elderly entertainment. The ideal game for use in stroke rehabilitation would satisfy all those criteria. They analyzed and compared two sets of games, according to these criteria: existing games currently used in stroke rehabilitation (chosen subjectively as the most entertaining for elderly users), and other popular games not currently used in this area, but that could have advantages over existing games for stroke rehabilitation, and thus could be adapted for this purpose. They concluded that current rehabilitation games lack entertainment qualities and popular games lack essential components for rehabilitation effectiveness.

Burke et al. [6] identified meaningful play and challenge as the game design principles important for upper limb stroke rehabilitation. Meaningful play emerges from a game in the relationship between a player's actions and the system's outcome [6]. They presented several games that have been designed using these principles, and evaluated them using questionnaires made to a small number of participants.

In the next subsection, we present a review on serious games for rehabilitation.

2.3.2 A Review on Serious Games for Rehabilitation

The work herein presented reviews relevant work described in the literature in SGHR, focusing single player and multiplayer prototypes. We make also a reference in each game to the evaluation test done, in particular, the size of the sample used in the test and the evaluation method chosen.

2.3.2.1 *Single Player Prototypes*

Betker et al. [67] describe a serious game tool for Balance Rehabilitation developed at the School of Medical Rehabilitation at the University of Mantoba, in Canada to improve dynamic balance control in a short-sitting position, for the treatment of problems caused by spinal cord and head injuries. The serious game tool includes three games that are controlled by using a center–of-pressure (COP) signal biofeedback as input device, and a flexible pressure mat containing piezoelectricity resistive sensors that is placed between the patient and the surface. The pressure mat is flexible enough to be placed on any type of surfaces: solid (fixed) or compliant, enabling to offer more difficult levels along with the parameters that can be adjusted by the game tool. Figure 1 presents an image of the patient sitting on the pressure mat. The pressure mat is connected to the laptop via an interface box. During the exercises, movement range and speed in all or targeted directions are exercised as patients shift their weight in the pressure mat. In the figure the laptop is displaying the game “Balloon Burst”.

Figure 1 - System setup: pressure mat (1) connected to the laptop by the interface box (2). The laptop currently displays the game. The pressure mat is currently placed on top of the SwisDisk (3); the Physio Gymnic (4) ball also is depicted [67].

Figure 2 presents screenshots of the games developed. Figure 2.a) represents the “Under Pressure” game during horizontal mode. In this game, the patient has to move the flower under the bee. Some information is displayed in the screen, such as: the total number of bees, the number of bees caught, and Medio lateral (ML) and anteroposterior (AP) movement ranges (in centimeters). Figure 2.b) presents a screenshot of the “Memory Match” game in which the patient has to select cards in order to find the pairs. Information about the number of pairs found and the ML and AP movement ranges (in centimeters) is displayed. Figure 2.c) presents a screenshot of the “Balloon Burst” game. In this game, the patient has to move the cursor over the balloon to pop it and sees the information about the total number of balloons, the number of balloons popped, and the ML and AP movement ranges (in centimeters) displayed in the screen.

The games enables the configuration of difficulty levels that can be manually or dynamically adjusted, helping to ensure patient competitiveness while exercising his full range and speed of voluntary movement. This is important to increase the player motivation, preventing frustration and loss of interest, and allows a customized and graded treatment program for individual player/patient. The games also provide instantaneous feedback to the patient as well as the therapist about performance and goal attainment.

The portability of the system affords its use in monitored at-home programs, which can make this therapy approach both convenient and cost-effective.

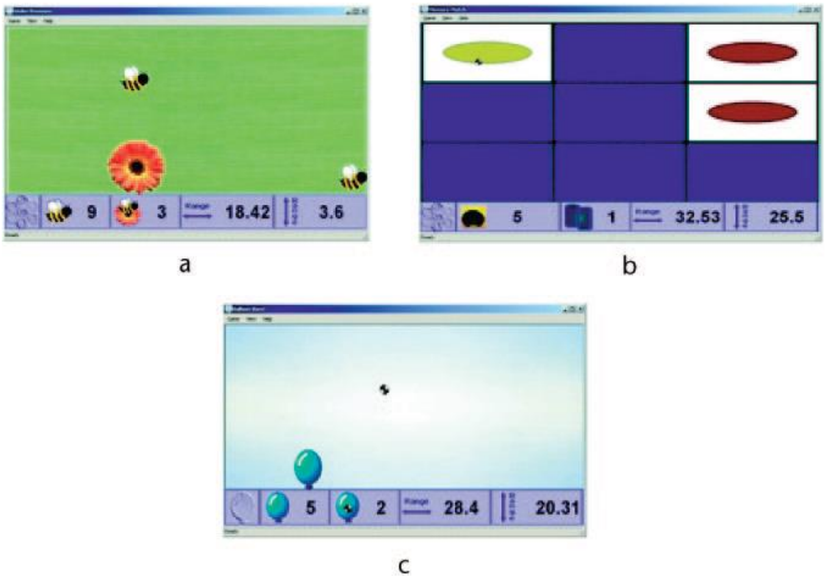


Figure 2 - Screenshots of the games. (a) Under Pressure during horizontal mode. (b) Memory match. (c) Balloon Burst [67]

The games were evaluated using a questionnaire on a sample of three patients with central nervous system injuries after the exercises and with stability measurements obtained during a set of tasks performed before and after exercise.

In Szturm et al. [68] the authors describe a randomized pilot trial conducted to evaluate static and dynamic balance control for people with balance impairments and reduced mobility using the serious game tool described in [67]. Patients in treatment (i.e., rehabilitation game) group are compared to those in control group that received a traditional rehabilitation program. In this treatment program, the patient stands on a fixed floor surface with progression to a compliant sponge pad, using the foot COP position signal that is acquired via the flexible pressure mat. This signal is mapped as input to the computer games in a way equal to using a computer mouse.

In Ma et Bechkoum [69], a serious game system developed at the School of Computing, at the University of Derby, in United Kingdom is described. VR games are included in therapy programs, which aim to encourage stroke patients with upper limb motor disorders to practice physical exercises. The framework the authors describe is presented in Figure 3 and uses functional tasks, such as wrist extension, reaching, grasping and catching, and serious games.

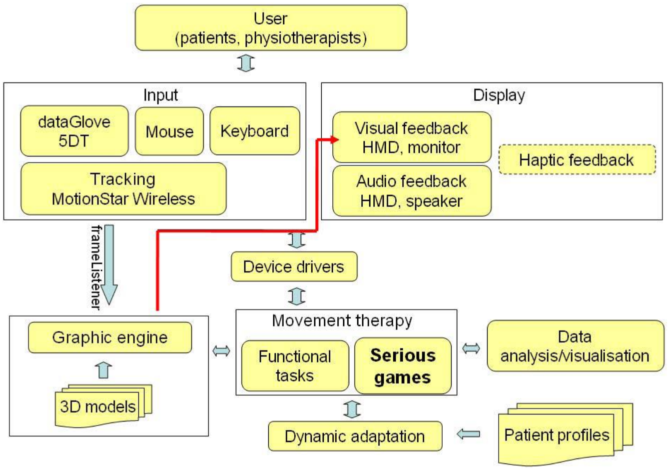


Figure 3 –A framework for serious games for movement therapy [69].

The system allows patients to interact with virtual objects in real-time through multiple modalities and to practice specific motor skills. Physiotherapists are necessary for initializing the system and controlling the scripting of tasks.

Input devices include the ordinary devices mouse and keyboard for the operator and a range of real-time motion tracking devices - data gloves to capture finger flex and hand postures; wireless magnetic sensors to track the patient's hand, arm and upper body movements. Output has visual, audio and haptic modalities. The dual output visual interface includes a desktop computer LCD for the operator and a high resolution HMD for patients. The HMD equipment displays an immersive virtual environment, providing a better sense of presence.

The software components include a 3D graphic engine and a movement therapy module, which creates functional training and non-functional serious games. It also includes a dynamic adaptation module to select tasks and initially configure the difficulty level of the tasks and games, based on recorded patient profiles and progress data.

Figure 4 shows the “Catch-the-orange” game, in which the patient has to catch oranges falling randomly onto a target area. For catching the oranges the patient holds a virtual basket, whose position and orientation are controlled by a sensor that is attached to a real basket, held by the patient with one hand or both hands. If the patient tills the basket, he may not be able to catch the oranges and the ones already in the basket may fall to the ground. Some parameters may be adjusted, such as: the target area on the X-Z plane, the falling speed of oranges, the time between oranges falling and the size of oranges and the basket can all be adjusted to suit individual patient’s needs.

Figure 4 -The Catch-the-Orange game: (a) screenshot of the game; (b) a user playing the game [69].

Figure 5 shows a fishing game in which the patient is in an underwater world using his hands to catch fish that are swimming randomly in the water. There are depicted in the screen two virtual hands that are a representation of the patient own hands through a sensor attached on each hand.

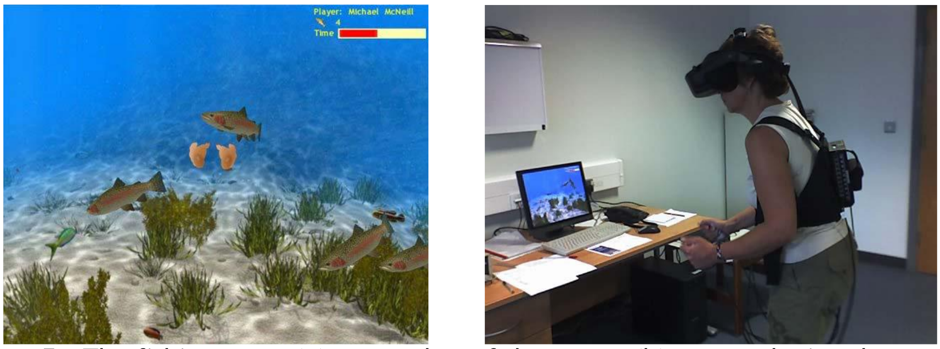


Figure 5 - The fishing game (a) screenshot of the game; (b) a user playing the game [69].

Figure 6 presents a screenshot of the game “whack-a-mouse”. In this game, the patient has to hit the mouse, while it is stationary, using a virtual hammer which is controlled by the position and orientation of a sensor attached on his hand. The mouse appears at a random location on the tabletop, stays there for a given number of seconds and then re-appears on another part of the table. Besides encouraging gross movement and improving accuracy and speed of patient’s upper limb movement, this game also enables the improvement of the visual discrimination and selective attention of the patient, which are important aspects of stroke rehabilitation when the patients exhibits hemi-spatial neglect.

A pilot study was made with eight participants showing that, accordingly to extensively used assessment methods (action research arm test – ARAT and motricity index - MI), despite the limitations of the study, it supports the effectiveness of the serious games approach.

Figure 6 -The whack-a-mouse game [69].

Conconi et al. [70] introduced PlayMancer, a platform for rapid development of serious games, intended to be applied to two application domains: physical rehabilitation, and therapeutic support and lifestyle management programs for behavioral and addictive disorders (i.e. eating disorders and pathological gambling). PlayMancer is actually a Games for health research project funded by the European Commission which aims to implement a framework and a platform for serious games by augmenting existing 3D gaming engines, reducing production and distribution costs. The platform has a modular architecture and combines techniques from multimodal interaction (motion-tracking, touch, speech and biosensors), 3D engines, virtual and augmented reality, speech recognition and natural language processing. The prototype to be adopted for chronic mental disorders treatment, introduces the patient to an interactive scenario that aims to increase his general problem solving strategies, self-control skills and control over general impulsive behaviors. The 3D game environment is made up of different islands where each island will permit access to one or several types of resources, which will facilitate and improve the game character, and thus the player's relaxation techniques and planning skills.

Caglio et al. [71] assess the modifications occurring in cognitive functions, in particular spatial and verbal memory in a Traumatic Brain Injury (TBI) patient after a 3D video game rehabilitation training. The game is a driving simulator. During the training, the participant is requested to explore a complex virtual town from a ground-level perspective using direction keys to interact with the virtual environment. Figure 7 shows an example view from the virtual town.

Figure 7 -Example view from the virtual town. (a) Aerial view; (b) example view taken from the video game [71].

Cameirão et al. [72] present the Rehabilitation Gaming System (RGS), a VR-based system for the rehabilitation of patients suffering from stroke and TBI. The system uses a camera based motion capture system and two data gloves to capture finger flexion and gaming technologies to activate intact neuronal systems that provide direct stimulation to motor areas affected by brain lesions.

Figure 8 presents the RGS. In the figure, the subject, with the arms rested on the table surface, faces a computer screen. The movements of his arms are visually captured by a camera that is on the top of the display using for the detection the color patches located on wrists and elbows of the subject. A pair of data gloves measures finger flexure. According to the movements of the user, there is an avatar that performs a task in the virtual scenario.

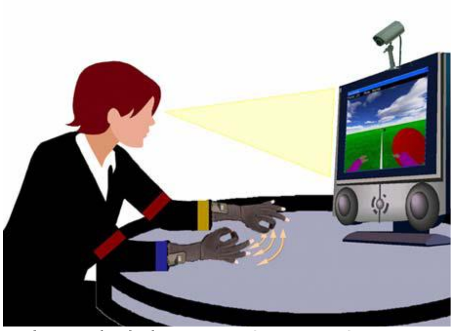


Figure 8 - The Rehabilitation Gaming System (RGS) [72].

The RGS is designed to engage the patients in task-specific intensive training tuned to the patients' needs and with continuous monitoring and adaptation [72-74].

RGS presents tasks of graded complexity. Figure 9 a) shows the "Hitting task" in which the patient has to intercept spheres that are flying towards him by hitting them with his virtual arms, to train range of movement, movement speed, and arm shoulder stability. Figure 9 b) shows the "Grasping task", in which the intercepted spheres can be grasped by flexing the fingers, to exercise finger flexure on top of movement range, speed, and arm and shoulder stability. Figure 9 c) shows the "Placing task" in which the grasped spheres can be released in the basket of the corresponding color, to train not only grasp but also release.

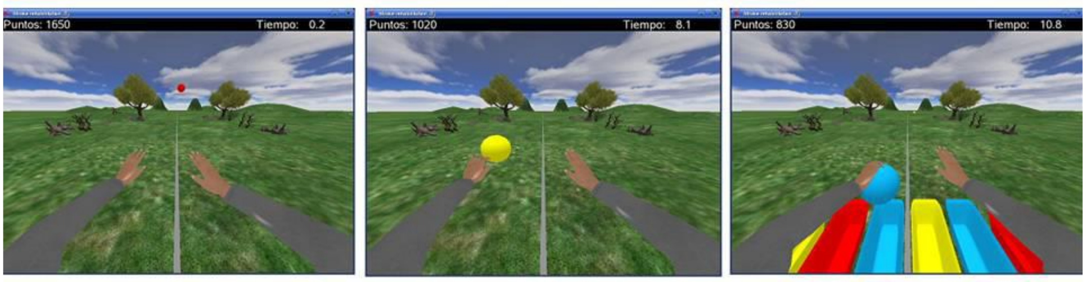


Figure 9 - The 3 RGS training tasks of graded complexity. (a) Left panel: 'Hitting' task; (b) Middle panel: 'Grasping' task ; (c) Right panel: 'Placing' task [72].

The authors [75] performed trials with 21 stroke patients and 20 healthy control users to study the effects of game parameters on task performance and developed a Personalized Training Module (PTM) for online adjustment of the task difficulty.

Ryan et al. [76] described the Balance Rehabilitation Games project developed at University of New South Wales (UNSW), in Australia, which aims to design a game to older adults while incorporating appropriate balance exercises. The game is a maze-solving problem for one or two players, which image is showed in Figure 10.

Figure 10 - The maze game [76].

In the game the goal is to navigate the maze and collect all the treasures. The player's score is the final time through the maze. Players move forward by walking in place on a Wii Fit balance board. Longer “strides” produce more rapid progress, to reward better balance rather over rapid stepping. The authors pointed as a future development the development of new versions comprehending cooperative and competitive two-player tasks. In the cooperative version, the players work together to collect all the treasures and finish the maze as quickly as possible. In the competitive version the treasures are omitted and it is simply a race to complete the maze as quickly as possible.

Brown et al. [77] developed a low cost rehabilitation glove for upper limb stroke rehabilitation to track fine motor skills. Six games were developed to train a range of rehabilitation movements from patients wearing the data glove, typical of those required in stroke rehabilitation. The glove picks up the signal from four diodes placed at the patient fingertips, using the capacity of the infrared receiver of Nintendo Wiimote. Only four diodes per glove are used since it is only possible to track four separated infrared signals per Wiimote.

Figure 11 presents the developed glove. The authors mention the intention to a future test of the rehabilitation system.

Figure 11 - Prototype glove device [77].

Burke et al. [6] developed several games, at the University of Ulster, for upper limb stroke rehabilitation, which use low-cost webcams as input technology to capture video data of user's movements. The position of the player hands is tracked, so he has to wear a glove or hold a marker which can be an object of a single color, such as a piece of card. The games use user profiling and an option to adaptability.

They developed three webcam games, named: "Rabbit Chase", Bubble Trouble" and "Arrow Attack". In "Rabbit Chase" the goal is to catch a rabbit as it peers out one of 4 holes displayed on the screen, as is illustrated in Figure 12.a). The player has to use one marker on either left or right hand to play the game. "Bubble Trouble" has two variations: one for single-handed play and the other for two-handed play. In this game a set of bubbles appear at random positions on screen within the player's range of reach and move in a random direction for a certain time before disappearing and the player has to touch these bubbles before they disappear, making them burst, as illustrated in Figure 12 b). In the two-handed play version, the bubbles are color-coded according the color of the markers and have an arrow icon overlay that depicts which hand the user patient has to use to burst the bubble. If he uses the wrong hand to touch the bubble, the bubble does not burst and the score is unaltered. The patient still has an opportunity to use the correct hand. This way, he is rewarded by a correct answer, but he is not penalized for an incorrect one.

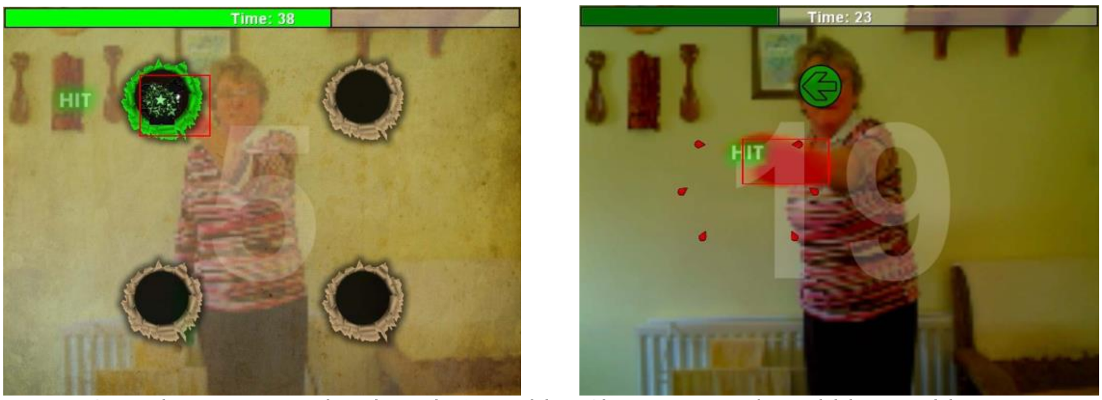


Figure 12 –Webcam games developed. **(a)** Rabbit Chase game; **(b)** Bubble Trouble game (two-handed version.[6]

In Arrow Attack game, two arrows are presented to the player, one pointing left and other pointing right (left and right arm, respectively). These arrows move between four boxes that are depicted on the screen. The player has to touch the two arrows simultaneously as they reach each box, with the correct hand, as illustrated in Figure 13. The colors of the arrows match the colors of the markers, so the player can distinguish more rapidly which arm to use.

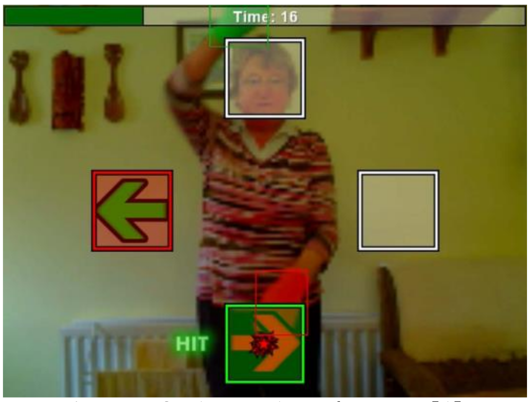


Figure 13 -Arrow Attack game [6].

After a limit time, each game ends and the player can see his progress with the game by means of a graphical representation of the player's score over the previous play attempts that shows in the end of the game play, as illustrated in Figure 14. The system permits the saving of previous scores that can also be viewed in the profile and log viewer tool.

Figure 14 -Score chart [6].

The authors also developed a tool for analyzing the log files recorded by the system during the game play. Figure 15 shows a pattern of the movement of a player for the two-handed Arrow Attack game, where the red color represents the left hand's movement and the green represents the right hand. In this case, we can see that the patient, which had left-side hemiparesis, in the moment of the game play failed to move his left hand to the top box. These games can also be played at home.

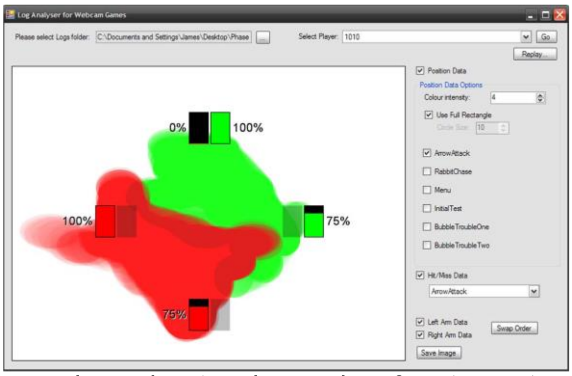


Figure 15 -Log analyser showing the results of an Arrow Attack game [6].

Burke et al. [9] extended the work presented in [6] to include augmented reality (AR) techniques for the developed upper-limb rehabilitation games. This has the advantage of using real objects to interact with the computer-generated environments. The real objects have attached AR markers and with a webcam it is possible to track the position and orientation of the real object as it is moved. The system can then augment the captured image of the real environment with virtual objects and then it is possible to present diverse games and scenarios to the patient. This has the potential to increase the engagement of the patient in the created rehabilitation scenarios. The real objects can vary in size, shape and mass which can promote to player acquire muscle strength and motor skills. Figure 16 a) shows an AR marker, and Figure 16 b) shows a virtual mug overlaid using the position and orientation calculated by the AR tracking algorithm.


Figure 16 (a) An AR marker in the real world**. (b)** A virtual mug overlaid.[9]

The first prototype they developed was a game similar to “Breakout” from Atari. There is a row of bricks at the top of the scenario. The patient moves a real world object with an AR marker attached to control a paddle. The row of bricks has to be cleared by rebounding a ball with the paddle. Figure 17 a) shows the real world scene.

The object, which the player uses to control the paddle, is augmented on-screen with a virtual cube that helps in showing in the virtual environment what the position of the object is. Figure 17 b) shows the real world image augmented with the virtual image in the game. This game helps in improving reach and grasps motions.

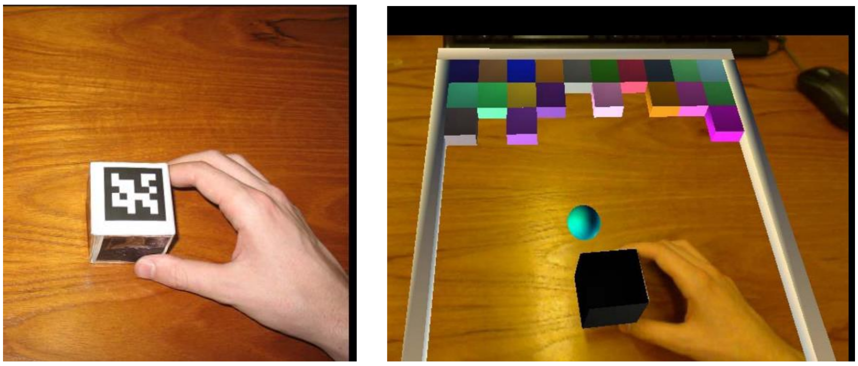


Figure 17 - Brick's a 'Break' game. (a) The real world scene. (b) real world image augmented with the virtual scene.[9]

The second prototype developed was the "Shelf Stack" game, in which the patient has several real world objects with AR markers attached and each of these objects has a corresponding virtual object. The patient has to put a designated object in a highlighted ring of a virtual shelve that shows in the scene, as it is illustrated in Figure 18.

Figure 18 - Shelf Stack game. (a) The initial selection of the object that must be picked. (b) The correct positioning of the object on to the shelf. (c) The correct placement of the object on the designated area of the desk [9].

Saposnik et al. [78] piloted a clinical trial with two parallel groups over two months to evaluate the feasibility, safety and efficacy of VR using the Nintendo Wii gaming system in arm motor improvement of 22 stroke patients, compared to the use of recreational therapy (playing cards, or bingo). The participants in the VR Wii group had a significant improvement in motor function, relative to the recreational therapy group. The authors argued in favor of VR Wii gaming technology as a potential effective alternative to facilitate patients in rehabilitation therapy to promote motor recovery following a stroke.

Bermudez i Badia and Cameirão [79] present an Internet-based game system – the Neurorehabilitation Training Toolkit system (NTT) – that enables to access kinematic movements and psychometrics, allowing the personalization of training objectives in upper limb rehabilitation, such as range of motion and movement smoothness. It is a software-based motor training toolkit that includes a PC or laptop, two mice and requires an Internet connection. It is accessed and executed as a web applet through an Internet browser, constituting a low-cost neurorehabilitation tool to enable patients to continue rehabilitation at home and after stroke. In the game, patients are confronted with a virtual scenario and they are required to perform in a repetitive way physical movements of varying intensity in order to complete the task which is performed on a tabletop. The game exploits a narrative structure to build a story around the training task, based on Freytag's classic concept of play and counter-play, and thus creating a sequence of plays and counter-plays that narrate the journey of the virtual character through an unknown environment, culminating with him finding home. In order to reach home, flying objects have to be collected by the avatar, enabling him to complete the different game levels. This aims to increase engagement and comprehension of training objectives and to deliver a sense of progress in the game. The authors analyze the interactions between game parameters such as: speed (the forward flying speed of the avatar), turning (turning speed of the avatar), acceptance radius (how close the avatar has to be to an object to collect it), and distance (distance between collectable elements) and relate these parameters with quantifiable training objectives, such as range of motion, coordination or movement smoothness and total arm displacement, to propose a model, generated with healthy user data, that enables to select game parameters in an automated way for an optimal training. For establishing the model, they performed four separate multiple regression analyses to find out how the game parameters contribute to the changes observed in previously determined kinematic measures. From this analysis they conclude that not all game parameters contribute to all movement kinematics which means that the set of game parameters that needs to be changed depends on the training objectives. In that sense, they implement a personalization training algorithm that adjusts the game parameters depending on the training objectives defined by the user. In a subsequent phase, the authors intend to validate the defined models with stroke patients at their homes.

In [80], Bermudez i Badia et al., present an extension of the NTT system to restore arm movement in severely affected stroke patients. The system integrates a VR training and a portable robotic myo-electric limb orthosis. The authors perform a pilot study to assess the acceptance and usability of the system with 3 chronic stroke patients. In [81], the authors use an hybrid BCI-VR system that combines a personalized motor training in a VR environment and mental imagery to monitor and promote cortical reorganization. The system is evaluated with 9 healthy subjects and data shows that users can control a virtual avatar in a motor imagery training task in which task difficulty is dynamically adjusted to the user capabilities.

Vourvopoulos et al. [82] present the distributed architecture and first implementation of the RehabNet, a motor and cognitive post-stroke rehabilitation system to be used at home, that can integrate input devices such as EEG, EMG and Kinect. The developed game is a motor and cognitive training game, consisting of a VR version of a cancellation task, implemented by using a representation of the paretic arm for navigation and crossing out the symbols in one or two dimensions. Faria et al. [83] describe the one-month long pilot study, involving three stroke patients, performed to access the impact of the RehabNet system, as a rehabilitation approach that merges cognitive and motor domains in single tasks. Patients performed repetitive arm reaching movements on a table top surface in a game-like VR adapted version of the Toulouse-Piéron, a widely used cancellation test to assess and/or train attention. Input devices used by the patients were: two natural user interfaces (Kinect for 3D movement and a custom made colour tracking software 2D arm movements) and two pointing devices (mouse for 2D and airmouse for 3D movements). Results support the holistic approach proposed by RehabNet system, sustaining interdependence on motor and cognitive recovery.

In [84], Vourvopoulos et al, present the design and implementation of a online game – RehabCity that is developed within the RehabNet framework. System was evaluated with 10 stroke patients and results showed high usability scores in what concerns effectiveness, efficiency and satisfaction. Authors made also an analysis of gaze behavior and observed that patients relied more on the goal list provided in the game than on the navigation map.

2.3.2.2 Multiplayer Prototypes

The preceding discussion demonstrated the reported benefits in respect to the adoption and exploitation of several interaction modalities within a rehabilitation context using games. In the described work, single user training systems and activities are addressed. The patient performs a task on his own and sometimes requires the presence of a therapist. However, to study the increase of motivation in the rehabilitation programs several approaches have recently been reported that seek to add a social dimension to gaming. Examples of these are described in the works presented in Vanacken et al. [85], Alankus et al.[62], Battochi et al.[86] and Anderson et al. [87]. In this context, family members and friends can also contribute to the rehabilitation process, by providing the desired social support, which can further enhance the patients' motivation. Such social support can also come from other fellow patients or therapists. Next we describe in general these approaches focusing in the games used. Later we describe how the social dimension is present and used in the referred works as an important factor for increasing motivation in the rehabilitation therapy.

A Collaborative Puzzle Game (CPG) was developed by Battochi et al.[86] at the University of Trento in Italy and at the University of Haifa in Israel to study collaboration and social skills in children with Autistic Spectrum Disorders (ASD) and with typical development. The game runs on the DiamondTouch (DT), an interactive table supporting multi-user interaction where the actions on digital objects can be performed only through simultaneous touch of two or more users. They follow an iterative approach during the design of the system that consisted in development, testing and refinement of the interface on the basis of observations made with users. They conducted two case studies, one with children with typical development and other with children with ASD.

The game is like a traditional jigsaw puzzle except that the pieces have a rectangular shape instead of the traditional interlocking curved shape, as is showed in Figure 19.

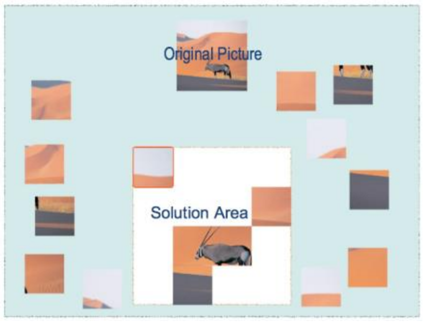


Figure 19 - Interface of the CPG [86].

The game starts by showing the following elements on the table surface: a variable number of puzzle pieces; a picture, representing how the puzzle looks like once correctly completed in the upper part of the DT; a solution area, placed in the area of the surface near to participants and horizontally centered, where participants have to drag the pieces to complete the puzzle. There is a setting panel where different parameters of the game can be defined such as: different play conditions, number of pieces, dimensions of the solution area, and the picture to be shown. The actions that the player has to perform consist in: dragging a puzzle piece to a new position, either to the solution area, or away from it. Whenever the player releases a piece in the solution area, it anchors to the cell of the solution area closest to the releasing position. The removing of a piece of a solution area implies to drag it away and release it at any other position on the surface. When the releasing is a piece that is over a previously released one, the first starts again to float around. It was also implemented some visual and auditory feedback to give more motivation and enjoyment to the interaction such as when a piece is released in a correct position on the solution area, a pleasant sounding beep is played and a green halo appears (and disappears after a few seconds) or when it is released in an incorrect position an unpleasant buzz is played and a red halo surrounds the piece until it is removed. Figure 20 shows an example of a joint action during a session of the game play.

A study was conducted to collect initial data about relevant behavioral patterns that result during the joint interaction of the collaborative game. The study included a group of 2 boys with ASD and a group of two boys with typical development and the preliminary results obtained showed that the use of an intervention tool like the CGP is adequate for these children and improves social interaction.

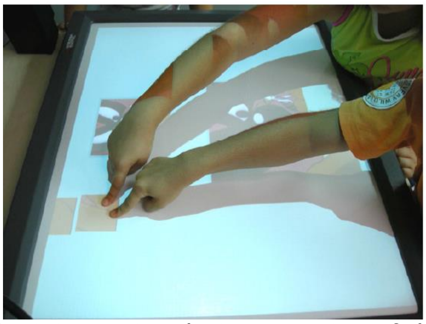


Figure 20 -Example of a joint action during a session of the CPG [86].

Vanacken et al. [85] designed at the University of Halster in Belgium and at Eindhoven University of Technology in the Netherlands, a collaborative training game for arm rehabilitation of patients with multiple sclerosis (MS). The game requires the patient to make specific movement tasks with his arm, using a force feedback device, the HapticMaster with a gimbal, illustrated in Figure 21. Additionally, it requires the collaboration of a co-player that will use a Wiimote or a force-feedback device.

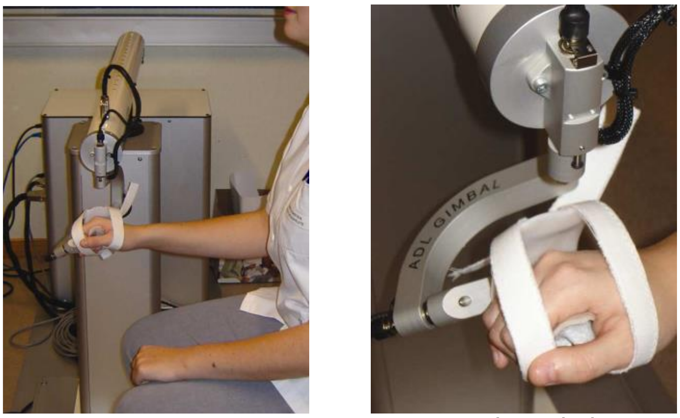


Figure 21 - HapticMaster with gimbal.

The advantage of using the HapticMaster is that it can generate large forces, which helps MS patients with more pronounced muscle weakness in the interaction. The patients do not have to hold the HapticMaster since is used a special gimbal in which the patient can strap his hand.

In this approach, the game developed serves as a proof-of-concept application: a two-player balance pump game, which is used to investigate if collaboration can be applied to increase motivation in MS patients. A graphical representation of the game is presented in Figure 22.

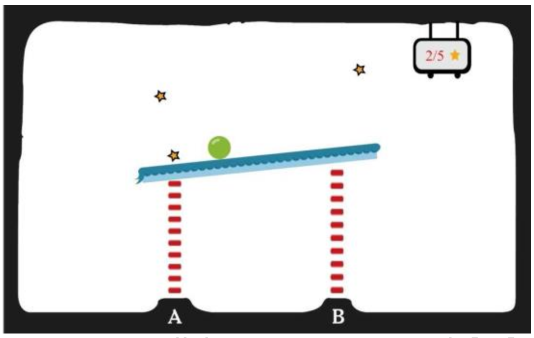


Figure 22 -Collaborative training task [85].

The goal of the game is to collect all stars by hitting them with a ball. The ball is positioned in a beam, whose ends can be controlled by one of the two players in the game. The ball moves by lifting both ends of the beam. The players can use a pumping gesture to move the ends of the beam upwards. When the beam has an inclination, the ball can roll and touch a star. Thus, the players have to collaborate in order to collect all the stars in the environment. The input devices used can be a force-feedback device to control the pump, or a Wiimote. When combining two force-feedback devices as input, two patients can train together. When combining a force-feedback device and a Wiimote, the idea is that the game can be played by a patient, using the force-feedback, and by a healthy player (can be a family member) using the Wiimote. Figure 23 shows a patient playing the game using the HapticMaster and a co-player using the Wiimote.

Figure 23 -Patient and co-player playing the game collaboratively [85].

As it is not always possible for the family members to come to the rehabilitation center during the hours that the patient has access to the force-feedback device, it was added a network support to the game developed, which allows the game to be played over a network in a remote setup at two distant locations.

The paper refers a user study that was planned in order to test and evaluate the potential of this kind of game in the rehabilitation process of these patients.

Alankus et al.[62] describe a study made at the Washington University in St. Louis and at University of California in San Diego, in which they design and user tested a series of collaborative and competitive rehabilitation games with 4 stroke patients and therapists to help these patients recover the use of their stroke-affected arm. Their long term goal consists in creating a game authoring system in which therapists can create or customize games for use by individual patients.

The games were designed to cover the space of arm motions. Four stroke patients participated in their exploratory study. During the sessions, they selected games they thought should be playable for each participant according to their ability to control the movement of their upper extremity. The games were adapted as much as possible to the participant's available motions and cognitive skills and the participants were observed as they played. A therapist also attended the sessions to evaluate the games from a therapeutic point of view. The problems identified during the sessions were used to adapt existing games and to develop additional games to better explore the domain of stroke rehabilitation games.

They developed, tested and improved nine games, two of them were two-player collaborative games, two were two-player competitive games and the remaining were single-player games. Here we focus the collaborative ('Dirt Race' and 'Under the sea') and competitive versions ('Catch the Kitty' and 'Pong').

'Dirt Race' is a two player collaborative game in which one player has to control a hand-operated windshield wiper to clear off the bugs of a truck that is driving through a locust swarm in a village. The other player has to steer the truck in safety.

'Under the sea' is a two-player collaborative game in which one of the players has to control a fish family (mother fish and its trailing babies) with a 2D input helping them to collect and eat ferns. This in turn will increase the number of points. The other player has to prevent the hungry predator from reaching the fish family. This predator is coming from off the screen to the right to eat one of the babies and the player has to control the snail that is moving vertically across the right side of the screen to prevent the predator from reaching them. Figure 24 shows an image of the game.

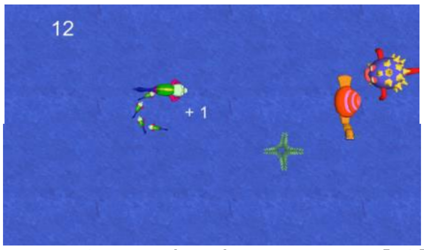


Figure 24 -Under the sea game.[62]

'Catch the Kitty' is a two-player competitive game where the players have to catch and move horizontally along the bottom of the screen the pets whose type is assigned to them and that are falling from above. Each player has to catch the pet type that is assigned to him or the shared pet type. In the later the score is higher. The goal is to test whether patients can translate vertical motion to a horizontal change in the game.

'Pong' is a two-player competitive game that is a remake of the classic game. The players have to control vertically moving paddles on each side of the screen to keep the bouncing ball in the field.

They used as input devices a webcam to track the positions of the colorful objects held by the patient and Wii remotes. Wii remotes have the advantage of being wireless and inexpensive devices. To detect compensatory motions, they attach additional Wii remotes to the body parts, as is illustrated in Figure 25.

Figure 25 -Wii remotes detecting elbow flexion and extension.[62].

At the University of Alberta, Canada, Anderson et al. [87] developed a rehabilitation system – Virtual Rehab, that consists of a standard Windows-based computer in conjunction with off the shelf Wii peripherals Wiimote and Balance board. The system tries to overcome a number of problems that prevent Wii from becoming widely adopted in rehabilitation such as the fact that motions and interactions are not focused on rehabilitation outcomes and game difficulty is calibrated to healthy patients, among others. Figure 26 presents the players interacting with the game.

Patients can use the virtual rehabilitation system in the hospital (with a therapist) or at home (monitored over the internet by a therapist). The virtual rehabilitation system contains four single/multiplayer games that were designed with specific target areas and disabilities in mind, focusing on increasing trunk control, lower extremity stability and patient balance. The activities can be customized to meet the limits of the patient mobility. The effectiveness and usefulness of the system is being evaluated in a local rehabilitation hospital.

Figure 26 - Patients interacting with the games in a (left) single player and (right) multiplayer configurations [87]

Ballester et al. [88] describe the use of an extension of the RGS system discussed in Cameirão et al. [72], including two low cost key-gloves and a multiplayer mode to test social interaction and its effects on the stroke rehabilitation process. Stroke patients played a memory card game in single player mode during one session and the same version of the game in multiplayer mode in the other session. The game trains cognitive (memory) and motor tasks (reaching and grasping).

2.3.2.3 Social features: competition, collaboration and handicapping

A patient committed with his rehabilitation program increases his chances of success. Motivation plays an essential role during rehabilitation therapy. The encouragement of patients throughout the rehabilitation process shows up crucial in achieving the objectives. For this purpose, it is essential to find a balance between work and entertainment, and it is necessary to make the therapy most fun, entertaining, appealing and additive.

Social interaction in video games showed positive effects in tests with healthy subjects, with respect to the gaming experience [85]. In this test the participants were 42 graduate and post graduate students, aged between 16 and 34 and played an arcade-like game in competitive mode using three alternated configurations in terms of social context: virtual co-player setting (participants were told they played against the computer, but they played against their partner, in separate rooms), mediated co-player setting (the pairs played online against each other in separate rooms) and co-located co-player (they played against each other in the same room and in the same console). Results showed that co-players contributed in a positive way to the player's involvement in the game.

The same can be studied with patients in rehabilitation through social interaction features incorporated in serious games, including collaboration and competition, making it possible to increase the degree of motivation and commitment of patients in the continuous practice of the exercises they have to perform [89].

Ballester et al. [76] found that a multiplayer environment affects positively the performance and enjoyment of patients during the task, since the patients displayed more effort in reaching when involved in a social task. Additionally, they observed that patients interact with the system much faster when using the new key-glove, comparatively with the use of the mouse and keyboard.

In a previous study [90] we made a literature revision on Serious Games for cognitive rehabilitation and proposed a set of social features to be incorporated in the games such as: collaboration and competition. In subsequent studies we added handicapping [91].

Collaboration

Through collaborative features, interaction between patients is promoted, the social bond is increased and a fresh gaming experience is provided. The goal is to form a team and patients to be able to act as such, serving to constantly support and being a source of motivation to other patients in the team. Although not yet a much discussed topic, several studies in this direction have already been made [85, 86, 92].

Competition

The competition features call for the competitive spirit of the patients. Here the goal is not to form teams but to play against adversaries. Two patients at the same level of recovery, or similar limitations are confronted by the best result.

Handicapping

However, a key aspect to take into account when it comes to competition is the disparity between patients. Different patients may have different limitations and can be at different stages of rehabilitation. As a consequence, it is not always an easy task to find two patients with the same type of limitations or in the same rehabilitation stage for playing together. However, it is important to create a way in which all these patients may play and interact in order to maximize the interaction and gameplay possibilities. Thus, it becomes essential to guarantee equal conditions for all participants. In this perspective, follows the handicap concept, or handicapping. Handicapping is a concept used in games and in certain sports as a way to match / even the probabilities for all participants win by granting advantages in the form of a one-off compensation or any other benefit granted to participants at a distinct disadvantage. The normal situation when employing this technique is to award a disadvantage to the most experienced player to allow the player with less experience to participate in the game, or sport in a fairly way. This technique is widely used in golf, chess, bowling, horse racing and polo, among others.

2.3.2.4 Commercial Systems in Cognitive Rehabilitation

The works reviewed until here are only prototypes, however there are some commercial systems that worth mention as these are widely used in many clinics or hospitals for cognitive rehabilitation, such as the RehaCom system [93, 94], the StrongArm System [95], the Parrot Software System [96], and the cognitive software of Fundación INTRAS [97].

RehaCom

RehaCom software is a system widely used and tested in the area of cognitive rehabilitation. Its effectiveness has been demonstrated in a number of studies all very well referenced (with a description of the study conducted) in the RehaCom Catalogue [93]. Since this system is well established in various hospitals and clinics, with a great number of patients, we can more easily have access to it and to the patients being treated by it in rehabilitation programs. For these reasons, we find it to be a reference system in this area and choose it as our case study to start building our games.

RehaCom is a computer-assisted modular system that requires an experienced therapist. The system concept was developed by Hans Regel in 1986 and since then it has been refined over 20 years in clinics, with input from experts in the area. Since 1996, it has been developed by

Hasomed. For a few years, it has been market leader in Europe [94] and is currently available in 15 languages.

The system is composed of training procedures for training different skills: attention, memory, executive, field of view and visuomotors. Each training procedure consists of a specific task that the patient must accomplish. Table 2 displays a classification of the games that presents the training procedures RehaCom offers for each training program or application area.

Table 2 - Procedures of System RehaCom by Application Area.

Attention Training		Memory Training	Executive Functions	Field of View Training	Visuomotor skills
Alertness	- Acoustic Reactivity - Reaction Behavior	Topological Memory	Shopping	Saccadic Training	Visuomotor Coordination
Vigilance	- Vigilance	Physiognomic Memory	Plan a Day	Exploration	
Visuo-spatial Attention	- 2D - 3D	Memory of Words	Logical Reasoning		
Selective Attent.	- Attention & Concentration	Figural memory			
Divided Attention	- Divided Attention	Verbal Memory			

For example in the category "Executive Functions", RehaCom provides the shopping game whose interface is shown in Figure 27 a). In this game, the patient receives a shopping list with all the items that he needs to find in the supermarket and put in his shopping basket. Once he has all the items in the basket, he can go to the till and leave the supermarket. Higher difficulty settings are achieved by increasing the number of articles to be purchased. In the second mode the article prices must be added up and compared with the amount of money that is available. In a "Plan a Day" game, presented in Figure 27 b), the patient has to schedule necessary activities in the best possible sequence. The patient is provided with a map showing buildings (bank, café, post office etc.) that must be visited according with the plan that he draws up, considering priorities, minimizing distance traveled and maximizing the number of activities completed.

Figure 28 a) shows the game "Attention and concentration" that is included in the category of "Attention Training". In this game, there is a matrix of pictures on the left and separated on the right a comparison picture. The picture on the right that matches the comparison picture must be identified.

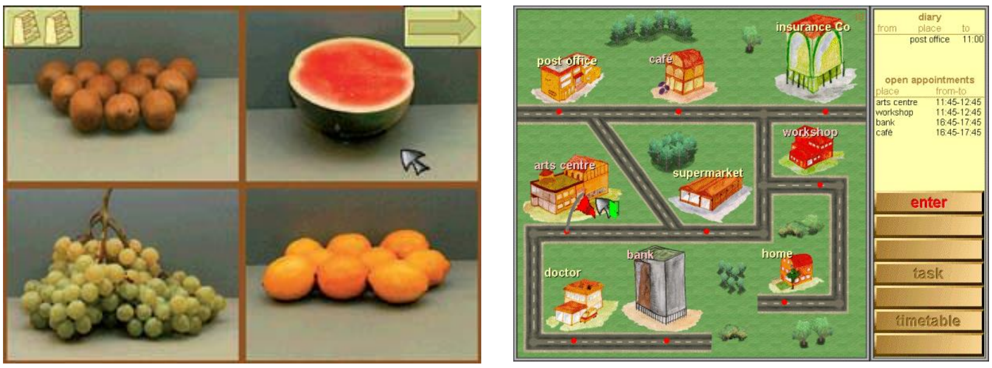
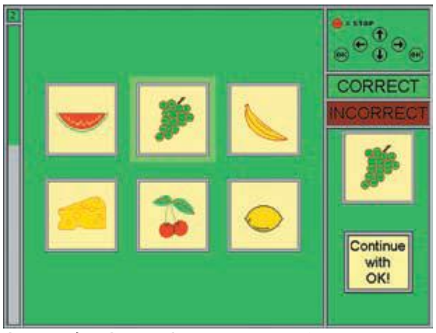


Figure 27 - RehaCom's games: a) Shopping; b) Plan a Day [94].

Figure 28 b) shows the “Memory for Words” game that is included in the “Memory Training” category. In this game the goal is to recognize words that were memorized in a first (learning) phase and that after appear in a sequence of other words.



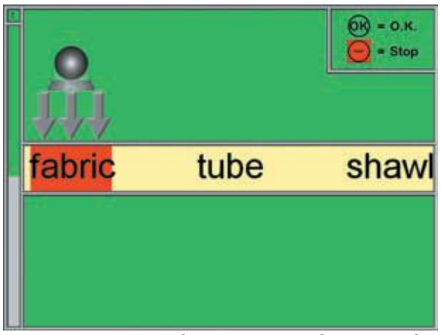
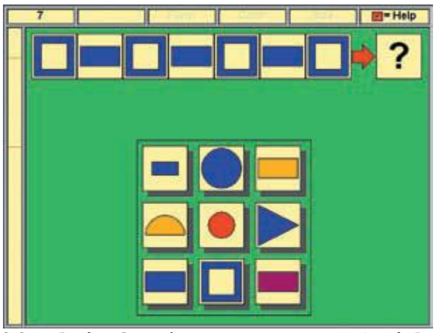


Figure 28 - RehaCom Games; (a) Attention and Concentration; (b) Memory for Words [94, 98].

Figure 29 a) shows the “Logical reasoning” game from the category “Executive Functions”. The goal is to select a symbol, from a number of symbols that are positioned in the bottom of the screen, which continues correctly a given sequence presented in the top. Figure 29 b) shows the “visuoconstructive abilities” game included in the “visuo-spatial attention” category.



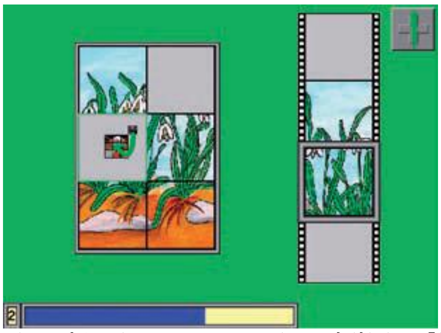


Figure 29 - RehaCom’s games: a) Logical Reasoning; b).Visuoconstructive abilities [94, 98].

In the Visuoconstructive abilities game, the goal is to reconstruct a picture. In the beginning, a picture is presented and the patient has to memorize as much of picture detail as possible. Then, after a defined period, or after the patient selects the OK button of RehaCom, the picture is broken down in number of jigsaw pictures and the patient has to reconstruct it.

Figure 30 a) presents the “verbal memory” game included in the “Memory Training” category. In this game, the patient has to answer to questions about a story that is displayed in the screen. The goal is to memorize as much detail as possible about the story to be able to answer the questions. Figure 30 b) shows the “Visuomotor coordination” game from the category “Visuomotor skills”. On the screen appears a dot and a circle, in different colours. The patient has to move the dot into the circle, using the joystick. Once he gets this, the circle starts to move along an unpredictable track. The patient has to track the movement with the joystick (represented by the dot).

Figure 30 - RehaCom's games: a)Verbal memory; b) Visuomotor coordination [94, 98].

RehaCom system offers a lot of advantages as described above according to the criteria defined, but it has some aspects of the games that could be improved mainly in the lack of the collaborative and competitive dimension and in the game interface which is very simple and is only two-dimensional. It is our intention to choose some of these games to build our games and to introduce new ways of interaction and a social dimension to the games.

This system is described in more detail in the next chapter because we find it to be the reference system in rehabilitation serious games.

COGWEB

COGWEB (Web-Based Cognitive Training) [99, 100] is a web-based software system for the training of cognitive functions developed in Portugal that allows the implementation of specialized programs of cognitive training.

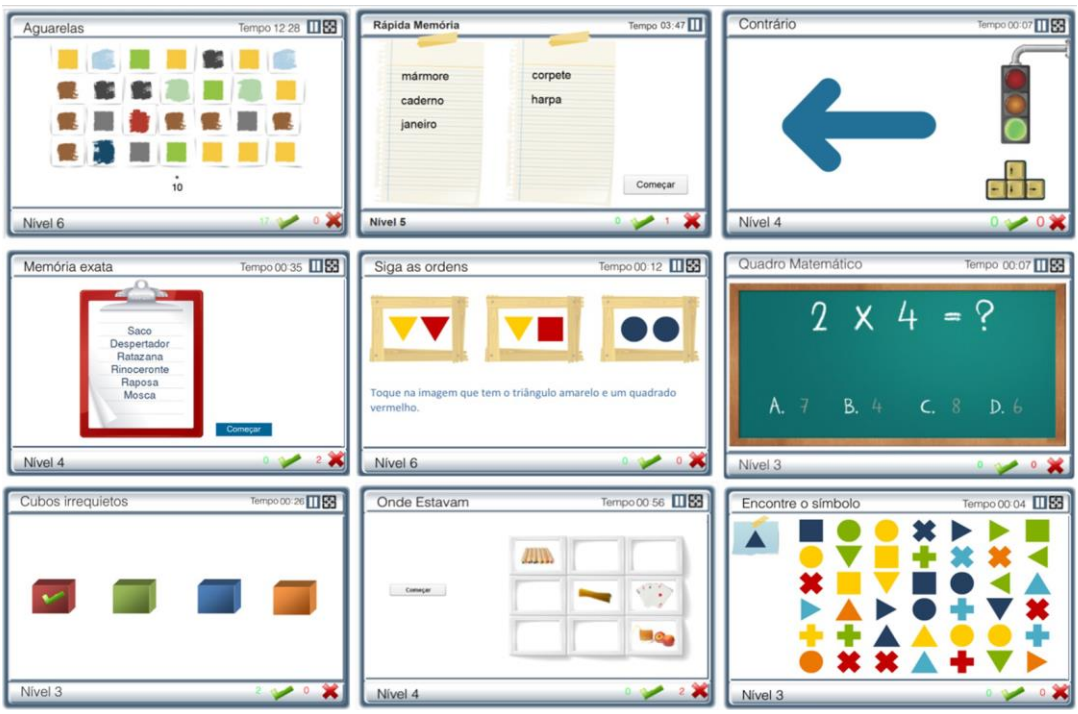


Figure 31 - COGWEB games [100] .

Currently it has a set of exercises developed for the intensive training of various cognitive functions, namely attention, memory, language, executive functions, calculus and constructive capacity. It is intended, in general, to all patients with cognitive impairments who are able to benefit from cognitive training programs and was implemented in a network setting involving the Portuguese mental health system and the hospital, academic, community-based institutions and professionals providing cognitive training.

StrongArm System

The StrongArm Systems Cognitive Rehabilitation Software [95] was initially developed for head/brain injury patients, but is now also used for other treatments like stroke patients, geriatrics, Alzheimer patients and children with learning problems. It can be used by at home, besides the rehabilitation centers or public schools and shows results of its efficacy evaluation from a controlled trial held during over 3 years.

Parrot Software System

The Parrot Software System [96], developed initially for speech rehabilitation, includes now different programs for communication, memory, cognitive reasoning, and attention rehabilitation, can be used at hospitals or rehabilitation centers or at home, providing an internet option as an alternative to purchasing the software.

Fundación INTRAS

Fundación INTRAS [97] provides programs of cognitive software (with modules for attention, perception, memory, orientation and calculation) for use in rehabilitation centers or clinics but also for home rehabilitation.

2.3.3 Summary

The present chapter discloses an overview of the SGHR field and identifies and discusses several open problems. We presented the main definitions of Serious Games, and how games interrelate with simulation. A comprehensive literature review on serious games applications, in particular within the rehabilitation domain, was presented. These applications included both the motor rehabilitation and cognitive rehabilitation. Cited works were divided into single and multiplayer prototypes. Additionally, a detailed analysis was presented concerning a social set of game features such as competition, collaboration and handicapping.

Chapter 3

Natural User Interfaces (NUI)

3.1 Introduction

In this chapter, we present a comprehensive review of the main interaction technologies associated with natural user interfaces, with references to their application in the rehabilitation area. At the end, we present the main conclusions derived from the literature review made on SGHR and on NUI.

3.2 NUI

Human-Computer interaction (HCI) is a very active research topic and a very important part of systems' design. Among its topics of study are: the analysis of the tasks that users can perform, technical and information requirements, ergonomics and the systems that can make the bridge between the user and the processes to be controlled. The study of the adaptation of technology to the interaction of people with disabilities is another key and challenged topic. Issues such as usability, accessibility and users' safety have always to be taken into account in the design and development of these systems. In P. Rego et al. [90], interaction technology was noticed to be an important factor that can influence game effectiveness in a rehabilitation program.

A user interface makes the connection between the user and the application system, determining its interactivity, accessibility and affecting significantly the user satisfaction with the system. In a traditional HCI system, the typical approach is to use a graphical user interface (GUI) based upon the WIMP (Windows, Icons, Menus, Pointing device) concept. The inputs from the user are typically the keyboard or the mouse devices, existing only one method of communication between the human (user) and the computer, or in other words, one mode or modality of input [101]. However, recent directions in HCI design are towards the use of new methods of interaction: intelligent/adaptive, multimodal and natural [102].

Natural User Interfaces (NUI) enable an interaction between humans and the computer based on the analysis of natural human behavior. Human actions are interpreted by machines as commands that control system operations [103]. This means that humans are able to use the system with very little practice and cognitive effort, through natural movements / actions, since these behaviors are deeply rooted in their daily experiences, reducing the cost of system use, time of learning, and time of getting used to the system commands, and as such making the interaction easier to handle and more intuitive [104-106]. The main objective of this approach is to interact with the computer the way we interact with the world [107], that is to mimic real-world interaction by using user body movements and actions similar to those used in the physical world to accomplish the same task and thus diminishing the artificial communication devices used for the interaction with the computer system. For example, using hand gestures, head movements, body motions, or spoken commands to make a selection on the screen is more direct than using the keyboard, or the mouse. Using these interfaces the user can interact with the system without noticing that he or she is using an intermediary interface (when using the Nintendo Wii Wiimote, or the PlayStation Move motion controller, for example), and in many cases the interaction can happen when there is no contact with any type of physical device [105] (when using body gestures to interact, for example).

NUI are an emergent area of HCI. Their capabilities are being exploited by industry manufacturers in their systems (as we can see by the example of Microsoft Kinect [2], Nintendo Wii [1] and Sony PlayStation Move [3]). There is no unique definition of NUI in literature. A natural user interface is composed by input devices other than the traditional keyboard or mouse devices, that gives the user the sense of an easier and intuitive interaction with the system, making him to learn more rapidly how to control the computer application [104]. According to Blake [108], a NUI is more than just the input as it may be used to interact, not just with a computer, but with any ambient device that may be e.g. embedded in our clothes, our house, or television. The author defines NUI as "a user interface designed to use natural human behaviors for interacting directly with the content". The final goal of NUI is that interacting devices become the objects of our daily life.

A study reported by Microsoft [109] to analyze how people around the world view natural and intuitive technologies, showed that 70% of the people enquired think that NUI can improve many aspects of life including workplace productivity, education, healthcare and other societal issues. This study was conducted to 6000 people across 6 countries and it can be noticed that healthcare is also referred as an important application area of NUI, providing greater access for persons with disabilities.

Many of the patients who use rehabilitation therapies present various physical limitations in addition to cognitive difficulties [69, 89]. It is therefore essential to decrease the limitations of games with respect to usability and interaction with the use of user interfaces, as much natural as possible and according to a multimodal approach [102, 110-112].

The multimodal term refers to the combination of multiple modalities, which in this particular case relates to the way the system receives its input / produces its output [113]. Thus, the multimodal approach is a combination of more than one interaction technology, such as input or output [107] that should serve as facilitator of the interaction between humans and the computer [102]. A multimodal interface can incorporate different combinations of voice, gestures and facial expressions, and other, more conventional, forms of interaction, such as mice and keyboards. The most common combination in the literature uses gestures and voice simultaneously [110]. Concerning the use of more natural forms of interaction, there is collaboration between different modes of interaction, as a way to support the signal recognition process. For example, capturing the lip movements can help in the speech recognition process [102]. An architecture [114] that accommodates the inclusion of several modalities as modules and also some previous studies [91, 104] on usability are described in [91, 104, 114]

Multimodal interfaces offer several advantages over more traditional user interfaces. Firstly, they provide a more natural and friendly user experience. For example, the Real Hunter System [115], an application designed to help users find houses, offers the possibility for users of pointing a finger at a house and make questions to the system about the house, using their voice [115]. Such combined and complementary interaction using gestures and voice illustrates the type of natural interaction experiences a multimodal approach can provide.

Similarly, a multimodal approach may be used in order to equip the system with redundancy which allows to open the use of the system to different people and in different circumstances [116]. The MATCHKiosk application [117], an interactive guide of New York, allows you to use voice or written input to perform searches on the city map. The users of such systems seem to prefer multimodal approach by the fact that the different types of modalities are more suited for different actions, thereby supporting each other and allowing alternative methods for people with different disabilities to interact with the system [118]. The use of these approaches is essential to develop systems for people with physical deficits, particularly regarding the movement of the upper limbs [119-121].

In adaptive interfaces, the system tries to adapt to the way the user experiences the interaction. User experience can be measured using several modalities of input, including biofeedback, information from voice, face and head. Brain signals contain information about user experience, along with other information measured from the body: bio signals such as heart rate, body temperature, respiration, and muscle tension.

In this section we start by presenting the main motivation for the use of natural user interfaces in general and then focusing in our domain of research: rehabilitation; next, we present the main input modalities associated to natural user interfaces, describing the main input devices involved, the main challenges and referring uses of NUI in several applications, focused in the rehabilitation domain of application. In the end of the section we present the systems that combine different modalities of input (multimodal systems), also focusing in the rehabilitation domain.

3.3 Motivation

Advances in the development of computer vision, speech and audio processing, along with development in hardware like inexpensive cameras and sensors has led to a growth in the research on a human-computer interaction more natural and intuitive.

Since the appearance of game controllers like the Wiimote, plastic guitars, plastic drums, mini-tennis racquets and Kinect, we are witnessing a change in the way games are played. From a simulation of actions on the screen to an imitation [122], where the player becomes the game controller, this change in game play has contributed to attract new audiences of game players and to the use of new game controllers as assistive tools in several areas of research. Players are able to control the games, not by using their fingers, but with their arms, hands, and/or the full body.

These new forms of interaction are becoming accessible through interacting devices increasingly smaller, present in several devices used in our daily life like mobile phones, pads, wearable computing (temperature sensors, heartbeat sensors, among others). These interacting devices are becoming increasingly ubiquitous which potentiates its use for rehabilitation and namely for serious games. It is very useful and more comfortable in rehabilitation to sense the temperature and heartbeat of a patient through a small device embedded in his clothes, instead of having him connected with cables to a computer device. The interacting device can thus be almost made invisible, mixed in patients' clothes.

Additionally, efforts in designing intuitive hardware devices as user interfaces are critical in game applications and in rehabilitation serious games in particular. We believe that the use of more natural user interfaces in the games can augment the motivation of the patients in the rehabilitation sessions. Patients in rehabilitation have cognitive and motor disabilities which difficult the interaction with the system. Eliminating or diminishing the use of artificial devices specific for interaction and enabling users to interact directly with objects of the real world (for example, using a racquet in a tennis game) without using an intermediary device, these interfaces enable an easier, intuitive, and realistic interaction. Additionally, natural interfaces alleviate users from the cognitive and physical load spent in the navigation task, freeing them to other activities of the overall task.

However, despite the natural interaction techniques make games more fun to play, there are other contexts where its use may not be so advantageous. For example, in a VR context, non-natural interaction is used to compensate for limited capabilities of the patients, since its use will allow him to access a distant object or to travel in ways not physically possible to him. Additionally, some natural interaction techniques result in significantly worse performance than non-natural ones. This could have to do with reasons like: the use of large muscle groups with more incidence that smaller ones; the use of sensors that are a mismatch for the steering task of the game, and problems of latency [123].

An additional aspect is the cost of the solutions. Work developments are being made towards the creation of applications that use low-cost devices to be accessible and affordable for people in general. In particular, in the Rehabilitation domain of area this is an essential aspect. The use of low cost systems can foster home rehabilitation and create more opportunities for the patients to train the necessary exercises in their recuperation plan.

Next, we present the main technologies that have been associated to the development of natural interaction techniques and describe some of the input peripherals that can provide a natural interaction experience to the users. Some of these devices can be used as low-cost solutions for rehabilitation games, not only for creating entertainment and fun games but also as assistive tools for several applications, as reported in several of the works reviewed in the literature.

3.4 Biofeedback

In general, biofeedback refers to a process of measuring biological signals (bio signals) emitted by individuals that enables them to learn how to change their physiological activity at will, mainly to improve health and performance [124]. It can be considered as a training technique that teaches an individual to recognize and modify his body's physiological signals [125]. These signals are measured using precise medical equipment that covers physiological activity such as breathing, skin temperature, heart function, muscle activity and brainwaves. These sensors return this information to the user, conducting to the desired physiological changes. Over time, these changes can eventually be supported without the use of a sensor.

Biofeedback sensors are widely used in different medical sectors since they allow an effective state analysis of the user body in a very short time and also have the advantage of being a non-invasive form of measuring that state. Biofeedback is useful in treating disorders and in rehabilitation programs [70]. For example, biofeedback can be used to help stroke patients regain movement in paralyzed muscles of the affected limbs, or to help anxious individuals learning to relax or to help patients cope with pain.

Biofeedback is thus a process that uses the physiological signs of individuals in order to manipulate and use them as a way of interacting with a system [73, 74]. There are two perspectives as regards the use of biofeedback-based technologies. On the one hand, physiological signals indirectly controlled by the user such as heartbeat and brain waves can be used. This perspective therefore refers to signals that cannot be explicitly influenced by the user and as such do not make up an effective interaction with the systems, due to the fact that are very restrictive in terms of gaming experience. On the other hand, the use of physiological signals controlled directly by the users (e.g. the flexure of muscles or breathing patterns) can be effectively used as a means of interaction, especially in people with difficulty in moving themselves [75].

Common forms of biofeedback are: Electromyography (EMG), Thermal biofeedback, Electrocardiography (ECG) and Electroencephalography (EEG) [126] [127].

EMG is a technique that evaluates and records the electrical activity produced by skeletal muscles when these are stimulated. The sensor used to measure the muscle tension is an electromyograph, which produces a record designated by electromyogram. The analysis of these signals can be used to detect medical abnormalities and in physical rehabilitation (stroke and cerebral palsy). It can be used to detect emotions when applied in the face [128]. The two main techniques that can be used to quantify the signal can be: intramuscular electromyography and surface electromyography. The intramuscular technique is more precise, although having the disadvantage of being invasive and potentially painful. Using the Surface technique, the sensors are placed on the user skin making this a safe, easy and non-invasive form of capturing the electrical signals [129].

Thermal biofeedback uses typically a thermistor (temperature-sensitive resistor) to measure skin temperature, usually attached to a finger or toe. This type of feedback can be used to treat chronic pain, edema, stress, among others. It can be used as a form of indirect interaction [130].

Electrocardiography studies the activity of the heart through sensors placed in the body. Although it is difficult to consciously control heart activity, heart rate can be used as a form of indirect interaction with games [130].

EEG is a technique, widely used in clinical and research settings, which records the electrical activity along the scalp produced by the firing of neurons within the brain, over a short time period, using multiple electrodes placed on the scalp. This technology allows then to detect the brain signals that occur when an individual performs a voluntary physical movement. This movement causes changes in the brain waves, which occur during the preparation of this movement (for example raise an arm). This technology can be useful for individuals with physical difficulties, since these changes precede the occurrence of the movement that is intended to be performed, e.g., the movement would not have to be executed, and it is only necessary to think about its execution [131]. It can be used in the diagnosis of epilepsy, coma, encephalopathies, and brain death. This method has a number of advantages over other methods: non-invasive, relative inexpensive and lightweight equipment, good temporal resolution (ability to detect changes within a certain time interval) and it is even possible to create wireless EEG headsets. Recently, more and more portable and wireless EEG devices became available. However, some drawbacks are the limited spatial (topographic) resolution and frequency range. It is susceptible to artifacts or undesirable signals in the EEG that can interfere and may change the characteristics of the brain signal used to control the Brain-Computer Interface (BCI), that are caused by other electrical activities, such as bioelectrical activities caused by eye movements or eye blinks and from muscles (EMG activity) that are close to the recording positions. Also, external electromagnetic sources can contaminate it, such as the power line [132]. EEG techniques were originally mostly used in different medical applications, BCI, and neurofeedback games. Neurofeedback (EEG Biofeedback) is a technique for training brain functions that uses real-time displays of electroencephalography to illustrate brain activity, often to control the activity of the central nervous system [133]. Studies have showed that neurofeedback can help children retrain brain wave activity, modifying it to appropriate levels (increasing or decreasing) and normalizing levels of concentration, impulses, attention and self-esteem adequate for their age [126].

Another form of biofeedback includes measurements of Heart Rate Variability (HRV) and Skin Conductance Levels (SCL), also known as the Galvanic Skin response (GSR), with sensors placed on the patient fingertips or earlobes. HRV measures an individual's natural changes between heart beats, SCL or GSR measures electrical conductance in the skin, associated with the activity of sweat glands and thus constituting an indication of psychological or physiological arousal. Results are given to the individual by a computer through audio tones, graphs, or video games [125].

Another form is the monitoring of respiratory changes (respiration rate) which is achieved through sensors placed on the chest of users who measure the rate and volume of respiration. Because it is easier to control, it can be used as a form of direct interaction with a system [130].

3.4.1 Brain-Computer Interfaces

Advances in sensor technology and computational capacities led to the development of brain-computer interfaces (BCI). The main goal of these systems is to enable the human-computer communication (or human-machine) only by analysis of human brain signals.

These systems translate the brain activity directly into control signals (output) to external devices or computers. The user then receives feedback on this output, which in turn is going to affect the user's brain activity and influences subsequent output. Figure 32 presents the BCI cycle, according to [134]. Brain signals are generated by the user whilst performing a mental task or responding to a stimulus. These signals are captured by specialized recording hardware and pre-processed in order to adequate them to the subsequent processing stages. Then relevant features to the task are extracted and classified, using machine-learning approaches. The results of the classification are sent to the game application and converted in relevant actions that constitute the new users' input and complete the feedback loop.

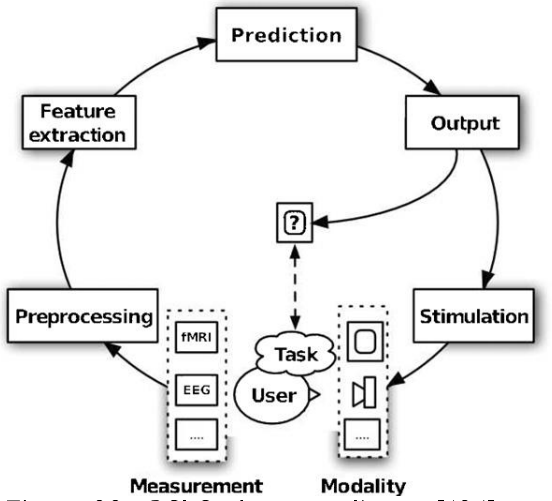


Figure 32 - BCI Cycle, according to [134]

The electrophysiological signals that represent the brain activity can be recorded using electrodes on the scalp (EEG-based BCIs), on the cortical surface (ECoG-based BCIs), or within the brain (intracortical BCIs). The signals are analyzed to derive particular features (such as EEG rhythms, amplitudes of event-related potentials, or firing rates of single neurons). These features are translated into commands that operate an output device, such as a word-processing program, a wheelchair, or a prosthetic limb [135].

In EEG based BCI, the brain activity can be read using an electroencephalogram (EEG) cap that has electrodes attached to it, to measure the activity in different brain regions, associated with different brain functions (perception, imaging, movement and affect). That information can be made available to a game engine that controls the environment, to adapt the game to a recognized affective state of the user, or to convert produced activity to commands that allow the player to change the environment, to navigate, and to make decisions to be successful in the game [136]. Figure 33 shows the typical elements of an EEG based BCI: the electrode cap with electrodes, a bio signal amplifier to which cables transmit the signals from the electrodes, an analog to digital converter for the brain signals and a computer for processing data and controls and for running the BCI application.

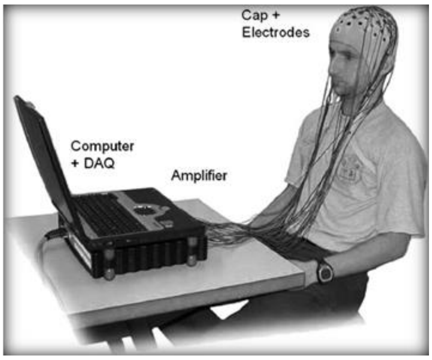


Figure 33 - A typical EEG based BCI [132].

Figure 34 presents a traditional EEG cap used in research (left image) and a helmet used in commercial applications (right image). Figure 35 shows the headset from Neurosky [137].


Figure 34 -(left) a traditional EEG cap; (right) Helmet used from Emotive Systems [138].


Figure 35 - Headset from Neurosky [137].

BCI enables that user cognitive resources can be fully used for the content of the game, instead of to the interaction with the interface. Also, the possibility of measuring the experience and affect of the player during the game and adapting the game to that affective state is an important issue. Games that adapt the game play to the affective state of the user have been designed [139]. In these games, the difficulty of the levels or the reward approach is changed, if the player becomes too frustrated or bored.

BCI have applications ranging from simple tasks (answering “yes” or “no” to questions, turning on the light/temperature, sending emails, accessing the internet, opening and closing a hand orthosis, or operating a motorized wheelchair) to more complex such as to operate a robotic arm or a neuroprosthetic limb that provides multi-dimensional movement to a paralyzed limb. The EEG-based BCI applications have been used to help disabled users to communicate with a machine [140, 141], in neurofeedback games [133, 142, 143] and in video games as game controllers [144]. Regarding to gaming applications, BCI can thus be considered one of multiple modalities together with mouse, keyboard, gestures, speech, among others [135].

This technology can improve the daily life experience of people with neurological and motor control disorders after stroke or other traumatic brain disorders, by giving information of the current state of brain activity. On the other hand, it may increase the efficacy of a rehabilitation program and improve muscle control for the patient, since the use of brain signals can supplement an impaired muscle control. Thus, for example, the patient with severe motor disabilities can use electrophysiological signals (such as electroencephalographic (EEG) activity or cortical neuronal activity), rather than through muscles, to indicate "yes" or "no" to control a cursor on a computer screen or to control a neuroprosthetic arm [135]. For these patients, the brain signals can be the only communication and interaction channel with the surrounding world. Also, BCI can be used to guide brain plasticity, by affecting motor learning, and thus restore more normal function of the brain [135].

Many neurofeedback games are used in treatment of psychological disorders such as Attention Deficit Hyperactivity Disorder (ADHD), Autistic Spectrum Disorders (ASD), Substance Use Disorders (SUD) including drug and alcohol abuse, since these are reflected by EEG distortions. An example of a neurofeedback serious game for concentration training is described in [145]. The game uses neurofeedback for encouraging the user concentration state by giving positive feedback if this state is recognized from the EEG signals. The EEG analysis method used for enhancing efficiency of the classification algorithm is based on fractal dimension model that can capture changes in brain state. Two EEG-based games (one 2D and 3D) were designed and implemented. Another example of a serious game for controlling the degree of attention is given in [146]. The game is entitled "NeuroWander" and has the form of an interactive fairy tale, where the user controls all situations in the screen through his degree of attention and meditation.

Motor imagery is a class of brain activity that can be used for imagining movements in game playing, without physically make them, that can be used as control commands to the external world (or game environment). This is a very important issue for patients who cannot move their hands or feet and patients with Amyotrophic Lateral Sclerosis (ALS) who cannot move or speak.

Another important aspect is that the brain areas activated by these imagined movements are also activated by the execution of the same movements and thus motor imagery can be applied, not only for disabled people, but also for healthy users, to control the game or a robotic device. When the healthy user consciously produces a movement, a brain pattern is activated. This brain pattern can then be measured and translated to a computer command, making possible to control the application. Also, it is possible to design games that use body movements as forms of interaction, but where the capturing of the body movement is done, not using cameras or sensors, but by measuring the associated brain activity. An example of the application of BCI for healthy users is the BrainGain Project which is a Dutch research project on Brain Computer Interfacing involving universities, research institutes, companies and patient organizations that aims to design and develop engaging games that allow, in addition to traditional multimodal input, interactions derived from brain activity patterns [147].

Figure 36 shows in (a) a BCI system used to interact with a VR application. The participant was asked to lift a virtual spaceship by imagining foot movements. In (b) illustrates an application based on VR technologies that enables users to visualize brain activity within the brain's volume in a 3D real-time stereoscopic virtual environment [144].

Figure 36 - (a) A BCI experiment; (b) Representation of brain activity in 3D [144]

Research has shown that using BCI instead of the traditional mouse and keyboard can enhance user experience by making a game more challenging, richer, and more immersive [148]. Most of the methods considered in BCI serious games are the Electroencephalography (EEG) and related methods since they are non-invasive, can function in most of the environments, have relative short time constants and require relatively simple and inexpensive equipment.

The availability of wireless EEG devices such as headsets that meet the consumer requisites for price, portability, wearability and ease of use, allows the use of EEG-based technology in serious game design and development. In games, BCI can be considered not just a substitute for the traditional input devices such as joysticks or gamepads but rather a complementary form of interaction, using brain electrophysiological abilities - the "think-and-play-mode" [144], along with the other forms of interaction. In multiplayer versions of games, users could even communicate and exchange mental information using a BCI, allowing the creation of new ways of interacting with each other [144].

Although the significant aforementioned benefits of BCI, the technology and its application have some problems and challenges to overcome yet. Further investigation will be necessary to better understand the human brain cognitive and psychological functions that could improve BCI systems and their use in computer games. Research must be conducted to study the influence of different virtual actions in brain processes and to explain the "BCI illiteracy" of some users that after many sessions of training can´t control a BCI with success [149].

Additionally, more research is needed to identify new brain signals that are more robust and reliable to control game environments, since no signal seems to dominate in a practical way: some signals are less immersive and only aid in selecting the target, and others (such motor imagery) are more immersive, but are too slow to act as control. BCI systems data transfer rate is limited compared to conventional human-computer media and requires a long period of training [144]. The final system setup should be efficient, robust, easy to use and easy to calibrate if it is going to be used daily. However, there is no standard defined for research environment.

An important observation is that the brain wave is a very weak signal and is affected by muscle artefacts when the brain wave is gathered, derived from motor actions. It would be necessary to develop new methods for brain signal processing to filter and extract features, since players still want to use motor actions [143]. The EEG acquisition should be robust and wireless to promote ease and comfort in the use of the BCI, an aspect that can be critical for many game applications. The selection of the best method of BCI for commercial computer games is thus a difficult task due of the several constraints on technology (required data rate, price, ease of setup, etc.).

An example of use of BCI in serious games is given by Liarokapis et al. [150] that uses brain-wave technology from two headsets (Neurosky and Emotiv) (Figure 34) for navigation and interaction in the 3D Roma Nova Serious Game (Figure 37). The SG is composed by Intelligent agents that are wandering in the gaming environment between predefined points of interest and where the avatar is controlled by the BCI devices.

Results showed that BCI devices offer the potential of being used as alternative game interfaces prior to some familiarization with the device and a certain degree of calibration, in some cases.

Figure 37 - User testing of the Roma Nova Serious Game integrated with BCI (Adapted from [150])

In order to incorporate BCI in multimodal interaction system, it would be necessary to make an effective and robust fusion between different modalities (brain signals acquisition system and other peripherals like tracking systems, haptic devices, among others). Despite the overall benefits of such a multimodal system, the approach opens new problems challenges that researchers will have to tackle.

3.5 Motion Capture

To detect and correct incorrect motion patterns during the rehabilitation exercises and/or to recover from several motor capabilities problems, it is necessary that the movements of stroke patients can be tracked. Therefore, devices that can accurately track the position of limbs in space are an essential component of a rehabilitation system. Tracking the motion of the human hand and arm has been investigated by many researchers and has many applications in rehabilitation. The success of motion-controlled game hardware and peripherals enables the application of games for rehabilitation, not only in hospitals and clinics, but also at home [151].

Motion capture methods can be categorized into two main types of systems: optical and non-optical [152]. Optical based systems use cameras to record images of the conductor and then extract information using image processing and computer vision techniques, normally applied to improve accuracy in position estimation. These systems can also be used to acquire information from positional markers attached to the human body [153] and have the advantage of being totally non-intrusive. However, they have limitations due to the field of view and the fact that can only capture visual information.

Non-optical systems, or sensor based systems, involve the modification of the equipment (or the conductors clothing) to contain sensors, such as accelerometers or magnetic positional sensors, to acquire non-visually observable data [153]. In the non-optical category of systems, we can consider more options: inertial, magnetic and mechanical motion capture techniques. Mechanical motion capture systems generally track the articulation of mechanical parts placed at body joint angles. Magnetic motion capture systems measure the relative magnetic flux of three orthogonal coils on a transmitter and receiver. Inertial motion capture technology is based on the use of inertial sensors and does not require external cameras, emitters or markers. In addition, due to improvements in the performance of small and lightweight micro-electromechanical systems (MEMS), inertial sensors are more widely used for the application of human motion capture. Also, inertial sensors are used widely for tracking arm movements and they have proven to be effective. Non-optical systems have the disadvantage of being intrusive, which can affect its performance, but can provide a greater range of data. Some of the factors that can affect the choice of the approach can be: variety of data, accuracy of tracking, expense and size and complexity of the system [153].

3.5.1 *Non-optical - Inertial based*

Examples of input devices that can be included in this category are the Wii Remote Controller, the Wii Balance Board, gloves with sensors and mobile phones with accelerometer.

Nintendo Wiimote

Nintendo's Wii was released in November 2006 [1] and since then has attracted people of all ages and disabilities, due to the ease of use of the controllers and the interactivity provided by the games. The Wii console system is composed of several controllers, being the Wii Remote controller, the Wii Sensor Bar and the Nunchuk the most used as assistive tools for rehabilitation games. Figure 38 presents the Wii remote controller.

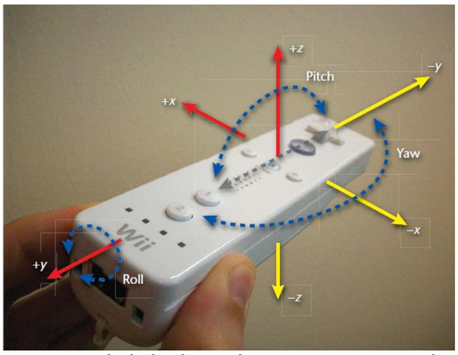


Figure 38 - The Wiimote, with labels indicating its coordinate system [154]

The wireless Wii Remote controller (or Wiimote) interacts with the player through technology that uses a motion detection system and an avatar (representation of the user in the computer). It incorporates several buttons and has a speaker, programmable LEDs, a rumble device (that causes the controller to vibrate, when activated), and an external connector for other input devices, like the Nunchuk and the Classic Controller [155]. It tracks motion and hand movement by an infrared (IR) sensor (with a resolution of 1024 x 768 and capable of tracking up to 4 simultaneous infrared sources) and uses a Bluetooth wireless connection to send the x, y coordinate data to the computer or Wii game console [156]. The Wiimote can detect acceleration along three axes using an accelerometer that responds to changes in direction, speed and acceleration and permits the user to interact with the games, performing wrist, arm and hand movements. The 3D acceleration data can be used to obtain data regarding the movement velocity. It can detect movement up-down, left-right, and can also control slowly forward-backward motion toward an object in a 3D game.

The Wii Sensor Bar has two groups of IR LEDs at fixed widths between them that enable the Wiimote IR sensor to determine its position relative to Sensor Bar and capture and reproduce on the screen the movement from the controller, performed by the user playing the game. When the Wiimote IR sensor points at a Sensor Bar and sees the IR light emitted by the LEDs of the Sensor Bar it occurs a connection. This produces IR blobs that the Wiimote tracks and reports in x and y coordinates, along with the blob's width in pixels.

Nunchuk can be connected to the Wii Remote controller via the external extension connector, enabling more flexibility in compatible games. The motion-sensing technology is similar to the Wii Remote controller, and it has with two buttons and a Control Stick, enabling to move characters around while the user is performing more specific actions with the Wii Remote controller.

The system enables up to four Wii Remote controllers to connect at once, enabling experiences in a multi-user context.

With the Wiimote, users use the controller in a similar way to the way they hold and manipulate real word objects. Additionally, they can see their movements on the TV screen, since the sensor measures the user movements and maps them into the virtual environment. This feedback generates a positive reinforcement and facilitates training and task improvement. The system also enables to reduce speed, making it useful for users with cognitive impairments after stroke. It also provides multimodal sensory feedback (touch, vision and auditory) with the avatar, enabling adjustments while observing and executing the diverse tasks proposed by the game [78]. The haptic feedback is the physical sensation resulting from interacting with the objects in the virtual environment. For example, in a tennis game, users feel a ball contacting with a virtual racquet. This sensation is improved with auditory feedback. The amount of feedback provided is changed by the differences in the applied forces and accelerations on the controller [157].

The Nintendo Wii console has been used in rehabilitation in the treatment of several impairments. Its use in rehabilitation is sometimes referred as "Wiihabilitation" [156]. Its success derives from the increased motivation it causes in patients, encouraging them to exercise movements of all the body. There are several works reporting the use of the Wii in rehabilitation [78, 157, 158]. Deutsch et al. [157] studied the feasibility and results of using the Wii and its Wii sports games software to augment the rehabilitation of an adolescent with Cerebral Palsy (CP), with positive outcomes. Loh et al. [158] evaluated the feasibility of using the same system to augment conventional therapy of stroke patients, in a non-controlled study, also with positive outcomes. Saposnik et al. [78] evaluated the feasibility, safety and efficacy using the Wii gaming system with entertainment software (sports and cooking packages) to improve arm motor function in stroke patients. These studies show that the use of the Wii results in similar improvements in functional outcomes, compared to conventional therapy and that the level of satisfaction and motivation reported by the users is higher using the Wii. The sport games (boxing, golf or bowling) are typically used in the rehabilitation sessions because they encourage training of gross movements [87]. Studies of balance and stability improvement typically involve the use of the Wii Balance Board.

However, the use of Wii has several problems, which prevent it from becoming widely adopted for rehabilitation, despite the much success it has had in rehabilitation. These problems derive of the fact that the motions and interactions it requires are not focused in rehabilitation objectives, such as muscle strength, or increase of range of motion; patients with physical disabilities often find these games too difficult or challenging, due to the fact that games are not specifically designed for rehabilitation, being calibrated to healthy users; progress monitoring is not made accurately because the scores and progress measurements given are too generic, and thus, insufficient for tracking the patient progress; in tele-rehabilitation scenarios, therapists cannot observe the patients progress and watch if they are accomplishing the recuperation plan (or are cheating); the feedback given to patients necessary to help guide or motivate their movements is not rehabilitation specific [87].

Besides developing custom applications to tailor the Wii game system with game tasks specific of rehabilitation, some authors also use physical custom setups using the Wiimote as the base of the game system to obtain more affordable systems. For example, Decker et al. [156] design and implemented a cost-effective and portable system for wrist flexion and extension involving a Wiimote, Velcro straps with reflective tape placed at relevant body locations, and an infrared LED circuit board. The inexpensive components of the setup make it possible to use at a home rehabilitation. Other studies involve the use of multiple Wiimotes [156]. Brown et al. [77] developed a low cost rehabilitation glove for upper limb stroke rehabilitation using the capacity of the infrared receiver on Wiimote to pick up the signal from four diodes placed at the patients fingertips and developed also the serious games to be tracked by the glove.

Nintendo Wii Balance Board

The Nintendo Wii Balance Board (an image is presented in Figure 39) tracks balance shifts within the stance of the user. It contains four pressure sensors positioned in each corner of the board. Pressure values for forward, back, left and right are computed from each pair of adjacent sensors. Point (0,0) is the center of the board. An overall weight value is also computed from the average of all the pressure sensors [153].

Figure 39 – Wii Balance Board [159]

Nintendo Wii Balance Board has been used in rehabilitation for improve balance and stability [76, 87, 160-162]. Sugarman et al. [161] report the feasibility of using the Wii Fit gaming system with the Wii Balance Board for balance training after stroke, with improvements of motion and balance showed in the patient involved in this pilot study. A separate study reported by Deutsch et al. [162] compared the use of the Wii with traditional treatments. The authors described a Wii based balance and mobility program using Wii sports and Wii Fit programs and compare it to a standard of care balance and mobility program for two individuals after stroke and found that Wiihabilitation treatments showed similar improvements in functional outcomes and greater levels of satisfaction of the patients.

Since the Wii and Wii Balance Board were designed to be entertainment systems, oriented for healthy users, different authors have developed custom applications using the Wii Balance Board aimed to users with impairments. However, most of these custom applications are still in conceptual designs stages and their efficacy needs further study [163]. Yet, Anderson et al. [87] developed a low cost virtual reality based system – the Virtual Wiihab that uses the Wiimote and balance board for movement precision, postural control or balance and stability, allowing activity customization and providing feedback (auditory, visual and haptic) and motivation to patients. Gil-Gomez et al. [160, 163] also designed and evaluated a virtual rehabilitation system for standing balance recovery named as easy Balance Virtual Rehabilitation System (eBaViRSystem) that uses the Wii Balance Board and provides task oriented exercises aimed specifically for Acquired Brain injury patients that were designed by clinical specialists. The system enables the therapists to customize at each session the duration and level of difficulty of the exercises, according to the needs of the patient.

Data Gloves

Data Gloves can be used as input devices to capture physical data such as bending of fingers, providing accurate data for motion capture that is interpreted by the software that accompanies the glove. Examples of these include: the CyberGlove [164], the P5 glove [165] and the 5DT glove [166]. There have been several studies involving the use of these gloves in rehabilitation. In Morrow et al. [164], at Rutgers University, the authors use a P5 glove from Essential Reality which is illustrated in Figure 40 (left) and (middle), connected to via an USB adapter to a Xbox after some hardware and software modifications. Each finger has one resistive bend sensor which measures the global bending over a range of 0 to 90 degrees. However, this glove cannot measure the individual joints of each finger, unlike the CyberGlove and has less accuracy. Additionally, it does not provide force feedback. In Golom et al. [166], the 5DT glove, illustrated in Figure 40 (middle), is connected to a PlayStation3 game console and used to study hand function in adolescents with hemiplegic CP. The game console is installed at their home, being remotely monitored.

Figure 40 (left) P5 glove [165]; (middle) P5 glove in use [164]; (right) 5DT glove [167]

Mobile Phones (with accelerometers)

Current mobile phone devices are available with accelerometer and its operating systems (Google's Android OS, Apple's iOS, Microsoft's Windows 10 Mobile) provide an API to control it, enabling the development of applications that can sense motion and react to the mobile phone orientation. Accelerometer can provide an inexpensive solution to create new interaction techniques that can be considered more intuitive and easy to use by the users of these devices. The accelerometer can detect the magnitude and direction of the acceleration relative to a frame of reference in free-falling, allows the sense of the orientation of the mobile phone. When these measures are combined with measurements read from the gyroscope, a device that measures directly the orientation of the device, the sense of motion can be made on six axes: left and right, up and down, forward and backwards, along with the roll, pitch and yaw rotations. Examples of applications that react to the orientation of the device are [168]: automatic activation of screen rotation whenever the user changes the orientation of the mobile device from landscape to portrait, or vice-versa; control the mobile device music player with gestures; in gaming, for navigating by tilting the device, rather than pressing keys or allowing users to turn-to mute an incoming call, pause the mobile music player or silence an alarm simply by turning the device face down. This accelerometer based input by tilting and shaking can thus reduce the number of key presses and the number of hands needed for the interaction. Other more advanced applications include using gestures through movements and tilting of the mobile phone to transfer documents and running interfaces to a large-screen display or distant display. The documents can be thrown from the mobile phone to a distant screen by tilt gestures, as illustrated in Figure 41, and can be fetched back by moving the phone towards the users body as is described in [169].

Figure 41 – User throwing a photo taken by a mobile phone to a distant display [169].

In mobile phones, besides the accelerometer, other inputs like the compass or the GPS can be used to recognize or contextualize other type of information.

Walters et al. [170] describes the use of mobile phones with a built-in accelerometer sensor in cardiac rehabilitation. Mobile phones, integrated with web services, measure physical exercise and collect information on physiological risk factors and other health information of cardiac rehabilitation patients, in a home-based care model, enabling to mentors to assess the patients' progress at distance. Spina et al., (2013) [171] present a sample application that is based only in smartphone-integrated sensors to monitor and access the performance of the rehabilitation exercises in patients suffering from chronic pulmonary obstructive disease.

3.5.2 Optical with markers

Compared to the use of gloves with several sensors providing accurate data for motion capture, optical (or camera based) systems provide a natural interaction. However, optical based methods have its own challenges, such as the accurate detection and segmentation of the face and body parts, hand and finger configuration, or detection of occlusions. Many of these challenges can be overcome by the use of several markers on fingers and body parts [172], or by restricting the environment and clothing. As an example, hand detection and segmentation can be made with or without the use of markers. Using markers, these can be single colored gloves worn on each hand, or gloves with different colors on each joint or finger. The markers make tracking easier and help to resolve problems of occlusions. Without markers, hand tracking presents a bigger challenge.

In this subsection, we present optical based systems using markers.

Sony PlayStation Move Motion Controller

Like the Nintendo Wii with the Wiimote [155], also the Sony PlayStation 2 with the Eyetoy [173, 174], the Sony PlayStation 3 with Eye [175] and the Sony PlayStation 3 Move systems have been introduced by the gaming industry with potential for use at home rehabilitation for training of motor activity. This technology uses a traditional camera (Eye camera) and an infrared emitter in the controller. The webcam detects where the player is pointing the controller. The detection can be made in 2D and then it is a position on the screen (like it was a mouse) or in 3D through triangulation methods to detect the distance from the controller to the screen. With accelerometer in the controller, it is possible to know its inclination and thus to know where it is pointing.

The Sony PlayStation Move system includes the PlayStation 3 system, the PlayStation Eye Camera and the PlayStation Move motion controller [3]. The Eye camera detects the coloured sphere at the end of the motion controller and tracks the positions and movements of the player. Figure 42 presents an image of the Sony PlayStation Move system.

Figure 42 - Sony PlayStation Move System [3].

Flynn et al. [174] report the use of the Sony PlayStation 2 with the Eyetoy as a low cost VR device for the rehabilitation of an individual after stroke as a home exercise program. Huber et al. [175] present research conducted at Rutgers and Indiana Universities on the development of a PlayStation 3 system for hand telerehabilitation of children with hemiplegia.

3.5.3 Optical without markers

In this subsection we present optical based systems without the use of markers.

Kinect System / PrimeSense sensing systems

Microsoft Kinect system (originally designated by the codename "Project Natal" [176]) was launched in November 2010 for the Xbox 360 video game console and enables the player to control the games with gestures and movements of the all body, eliminating the use of input game controllers [2]. Besides full body 3D motion capture, it also has facial recognition, and voice recognition capabilities. Kinect motion sensor device contains a simple RGB camera, an infrared source, a multi-array microphone and a custom processor that uses proprietary software. The camera and infrared source are used to detect motion and measure depth [176]. The RGB camera and 3D depth sensors (infrared camera) adapt to the player's environment, mapping the environment into a 3D depth image (depth map) and then locating the player's body and mapping to a parameterized skeletal model which can then be used to control games on the console. The depth map provides an image of the scene in front of the Kinect in terms of the distance from the Kinect to the objects, giving additional aid to distinguish gestures, players, etc. The player full body (hands, wrists, arms, legs, knees, waist, hips ...) can act as a controller of the game, without requiring to hold any other interface device or to move on a pad. It enables facial recognition by collecting physical data that is stored in user's profile. It also permits voice recognition and acoustic localization [176], using four audio microphones within the sensor to recognize and separate the user voice from the other noises in the room, so the user can e.g. control games with his voice. The system enables also that multiple users can be tracked for both competitive and collaborative activities [2].

Microsoft released a non-commercial Kinect software development kit (SDK) for Windows on June, 2011 which includes APIs, sample code and drivers [177] An image of Kinect system is presented in Figure 43.

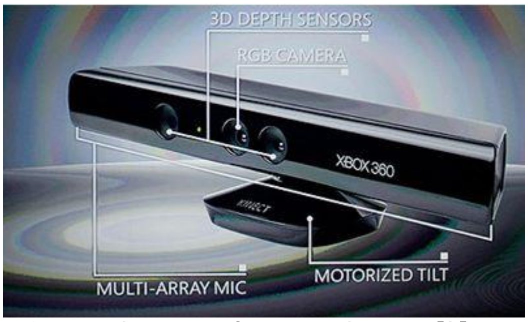


Figure 43 Microsoft Kinect System [2]

Kinect can be used in health and rehabilitation applications in several scenarios. One scenario is described by Gallo et al. [178] for medical image data exploration where hand and arm gestures can be used to interact at distance. This application is suitable for use in operating rooms where non-sterilizable devices cannot be used as the user interface is touch-free and does not require complex calibration steps. Tan et al. [179] describes another application of Kinect in surgery where the visualization of 3D computerized axial tomography (CT or CAT) images is controlled using Kinect sensors, without moving the mouse. Students at University of Washington's Biorobotics Lab [180] use Kinect to explore the idea of how telerobotic surgery could be improved by incorporating the sense of feel. In the video demonstration, Kinect is connected with a Phantom Omni haptic device that gives force feedback to its user. The 3D models of objects captured by Kinect are visualized and the data is converted into haptic feedback that other student, remotely located, can feel. The idea is to build a system where a surgeon would have information of no-cut zones and these barriers could be felt when the surgeon was performing robotic surgery.

Another application is the use of Kinect in cardiac rehabilitation [181]. During the Health and Wellness Innovation 2011 activity, Ryan Orendorff built a prototype system – The Exoma Exercises System [182] to increase the adherence of patients suffering from heart failure or invasive cardiac surgery to practise cardiac exercises, normally considered as boring using current approaches. The system uses Microsoft Kinect hardware and computer vision algorithms to track and quantify the patient's exercises performance. During the exercises, patients wear physiological sensors to track heart rate and blood oxygenation and try to achieve higher scores as they receive immediate feedback of their state. Although currently the system is tracking simple rehabilitation cardiac exercises, next version includes adapting the feedback into a 3D game, incorporating physiological sensors and planning strategies to maximize the impact of feedback.

Chang et al. [183] describe the use of Kinect in physical rehabilitation involving two young adults with motor impairments. The pilot study showed that the participants improve exercise performance during the intervention phases and that their motivation for physical rehabilitation has increased.

3.6 Speech Recognition

The audio-based technologies deal with information from several sound signals. Although the nature of these signals is not as diverse as visual signals, the acquired information may be more reliable and useful [102]. Several technologies emerge under this modality.

Historically, speech recognition [56] has given prominence by researchers. Scientific research related to the treatment of audio signals have been working in what is one of the biggest challenges of speech recognition, the development of systems capable of operating well in noisy environments. Speech recognition in game environments is a major challenge since the recognition process has to be made typically from a noisy background that includes loud and enthusiastic voices of different users (young, old, female or male) [184]. For that purpose, technological advances have focused on improving the accuracy and the ability of systems to give meaning to the words in the natural language of human [185].

Speech recognition (or automatic speech recognitions) allows the interpretation of spoken commands to be used, for example, as a system control method [186], or in transcription. The speech recognition process can be decomposed in the following steps [187]: recognition grammar (definition and specification of the speech input and its pattern to the speech recognizer); phoneme identification (analysis and comparison of audio signals to the language phonemes), word identification (the sequences of phonemes of previous step are compared to words and patterns that make up the recognition grammar) and output of the words detected. The output produced is the best “guess” of the speech recognizer from the user input.

Speech recognition technologies can be divided in two main categories of [188]: speaker-dependent and speaker-independent. Speaker-dependent requires that each user enters in a process of training to make the computer recognize his voice before using it. Speaker-independent overcomes this process by training the system with a set of speakers in the development phase. The term “voice recognition” is used for recognition systems associated with a particular speaker, as in the case of most desktop recognition software (e.g. Microsoft Speech Recognition SDK).

For several years the audio-based technologies deal not only with voice recognition, but make also use of other sounds made by the human vocal apparatus than voice such as whistles, whispers, groans and hums, among others [189, 190]. This form of interaction with the systems has proved effective with regard to the control of the mouse cursor [191] and in emulation of keyboards [190, 192], as well as a form of interaction in games [193, 194]. Sporka et al. [194] adapted the common Tetris game to take both verbal commands and non-verbal. Verbal commands passed simply by users say "left" to move the pieces to the left or "right" to move to the right, while non-verbal commands are characterized by a kind of groan ("hmmm") that with a higher tone shifts the pieces to the right and a lower tone would shift the pieces left. Overall, the study participants found the intervention methods much more fun than by using typical keyboards and commented that these methods would be greatly appreciated by users with mobility difficulties. Results suggested that non-verbal controls were shown to be more accurate and likely to execute faster.

The attempt to integrate human emotions human-computer interaction led to the analysis of emotions through voice [195, 196], another field of research in the area of capture and analysis of audio signals. What this technique aims to do is to automatically identify, from the voice, emotional or physical state of the user [196]. You can identify emotions from annoyance, anger, boredom, fear and indifference, among others [196]. This technology is currently used for example in reservation systems of automated tickets, scheduled to see if the user shows boredom or frustration, and changing the answer in function of that [196, 197]. There are also studies in medicine, where therapists apply this technology in the detection of signs of depression and suicide risk [198, 199]. Also other non-verbal sound signals, typically human, as sighs have been analyzed in order to improve the analysis of emotions through audio [200]. A study of Kostoulas et al. [201] describes the implementation of a speech interface, as part of a platform for the development of Serious Games (PlayMancer platform) for patients with mental disorders, which has two components: voice recognition and recognition of emotions through voice. For both components, positive results were obtained in terms of performance.

The use of verbal commands to control games and dialogue with virtual characters in game environment adds a new dimension to game play. Speech input gives the player a more natural control in game environments. Additionally, speech, along with facial expressions, is very important in transmitting users' reactions or their affective state. Experimental results show that performance of speech recognition in some games is more accurate and faster [202], besides freeing the hands of the player and promoting a hands-free interaction.

An overview of video games including speech recognition is given in [184]. Multimodal systems using different combination of interaction inputs can be found in the literature: gaze and voice [188], hand gestures and speech [202]. An example of using speech recognition in rehabilitation is presented in [70].

Speech input/output is present in most games for the major games consoles in the form of high-level commands, contributing to enrich the experience of game play. And we expect its use will be accelerated by the introduction of more powerful hardware, providing more complex speech interaction with a larger vocabulary, more natural language processing and more artificial intelligence (AI) technology, to allow players to issue commands in many different forms and be understood. Additionally, advanced AI technologies can enable the creation of game environments where human players collaborate/dialogue with virtual players in order to gain information and game strategy [184] and where emotional content derived from vocal intonation could be added and play an important role [203].

3.7 Haptics

The forms of interaction with a system must take into account the response of the system itself, or the system outputs and thus enable users to receive system information also through various methods, for example by sound effects and graphics. The haptic technology is an example of output feedback that is based on tactile feedback, through the application of forces or vibrations to users [204]. This technology is often used in robotics and virtual reality. Force-feedback can contribute to increase the realism of the game and make the user/patient closer to the environment of the game.

A haptic interface is a user interface that enables users to have touch interaction with virtual or augmented environments. The touch sense, being a parallel channel to seeing and hearing, can be used to give additional information to the user, contributing even further to give immersion and realism in game experiences. Haptics is used to describe concepts associated with human perception and understanding through the sense of touch. The term haptic derives from the Greek term “haptesthai”, which means “to grasp”, “to touch” [205].

Examples of haptic devices are e.g. Braille displays, vibro-tactile gloves or mice. Haptic devices produce sensations to the muscles and skin through touch, weight and relative rigidity [206]. They allow to mimic real touch sensations when using the computer. The sensations produced can be tactile or kinaesthetic [207, 208]. Tactile sensations are perceived through stimulation of the skin, as in a Braille display. Kinaesthetic sensations are perceived through sensing the body muscles, tendons, joints and their orientation in space, as in a force feedback display. Haptic devices can be classified in [207]: vibrotactile devices, force feedback systems, distributed tactile displays and surface displays.

Haptic technology emerged from robotic industry due to the need to operate robots remotely and to feel what the robot felt in the situations it was exposed. Haptic devices can be used for training applications in simulators (flight simulators, medical simulators), applications for the disabled people (training of hearing impaired or presenting information when the user doesn’t see well [207]), 2D and 3D modelling, kiosk interfaces and in gaming and virtual reality. Besides vibration and force feedback, advanced haptic simulators can also provide proprioceptive information, by tilting the player’s body.

The most commonly used commercial force feedback devices are the PHANToM force feedback devices and the CyberGrasp with CyberForce [205, 208]. The PHANToM force feedback devices (have different models with different sizes and force capabilities), often used in research, and providing six degrees-of-freedom (DOF), use small step motors and wires to convey forces to a user finger. The user can sense and manipulate virtual models through a stylus in a pen shape or by inserting his finger in a thimble, with only one point of contact at a time, resulting in a limit amount of transmitted information at a given time, although allowing the recognition of simple 3D objects. A model of Phantom device is presented in Figure 44.

Figure 44 - The Phantom device [209].

The PHANTOM Omni model of Sensable Technologies PHANTOM product lines is the most cost-effective haptic device available today and is presented in Figure 45.

Figure 45 - Phantom Omni model [210].

The CyberGrasp combines a data glove (CyberGlove) with an exoskeletal structure that provides force feedback to each of the user fingers, enabling thus five DOF force feedback, one DoF for each finger. It includes two types of haptic data: grasping and kinaesthetic. The first type consists of 22 angle sensors, 3 values for hand coordinates in 3D space, and 3 angles for hand orientation. The kinesthetic data includes 5 sensors for measuring the force applied by each finger [211]. CyberGrasp glove is presented in Figure 46.

Figure 46 - CyberGrasp [212].

Unlike the Phantom device which constitutes a more expensive technology, and prohibitive for home use [213], there are other more affordable devices providing force feedback e.g. the game controller Falcon [205] from Novint Technologies presented in Figure 47, a very popular consumer 3D touch device, that enables to control a game in three dimensions and also force feedback in three degrees of freedom, letting feel the objects texture, shape, weight, dimension, and dynamics.

Figure 47 - Falcon game controller [214].

Other low cost and commercially off-the-shelf (COTS) tactile devices are e.g. commercially force feedback joysticks and steering wheels.

In Figure 48 are presented two classes of force feedback devices: on the left, the Phantom device as a specialized and expensive force feedback device and, on the right, the Microsoft force feedback steering wheel as a COTS device. Uses of these devices in rehabilitation are described in [213, 215]. The Phantom device is used in [215] for rehabilitation of upper-limb dysfunction. The Microsoft steering wheel, originally developed for racing games is used in [213], in driving simulators for rehabilitation of patients with traumatic brain injury and patients post-stroke.

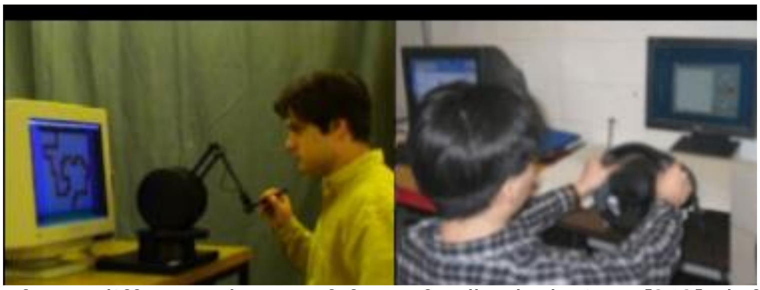


Figure 48 - Use of two different classes of force feedback devices [213] (left) specialized devices (right) COTS devices.

In touch-enabled games, players can have sensations as the object's shape, texture and weight and force effects when hitting a ball. Others enable to feel impacts from explosions, weapon recoil, impact of landing on the ground or bumping into a wall [205]. These sensations enhance the user's sense of presence.

3.8 Tangible User Interfaces (TUI)

A tangible user interface uses physical objects as user interfaces. The user interacts with digital information using physical objects of the real world. Tangible surfaces are capable of being perceived especially by the sense of touch. One of the pioneers in tangible surfaces is Hiroshi Ishii of the MIT Media Laboratory who leads the Tangible Media Group. According to Ishii et al. [216], digital information can have a physical form, with bits capable of being directly perceptible and manipulable and enabling a bridge between two different worlds: bits and atoms. ReacTable [217], a musical instrument based on a tabletop interface, constitutes an important example for the commercial use of TUI systems. In ReacTable, users can set up instruments interactively, by placing different objects and configure/parameterize them by using rotating gestures and touch input. Figure 49 presents an image of the ReacTable system.

Figure 49 - Reactable: a commercial instance of a tangible interface [217]

There are several examples of the use of TUI systems in the rehabilitation domain. A relevant example is given in Annett et al. [218], who describe the development of applications for motor rehabilitation based on a multi-touch tabletop screen, providing tasks that closely mimic existing rehabilitation activities. Pridmore et al. [219] uses TUI in the rehabilitation of activities of daily living for stroke patients, providing different mixtures of digital and physical information. The authors produced a first version of an integrated mixed reality system where users can complete the task of making a hot drink and control activity using a variety of interface methods including a touch screen system and a tangible user interface. Compact sensors were used to retro-fitting real kitchen artefacts and machine vision techniques were applied to the recognition of individual objects. Sharlin et al [220] describe the use of a TUI as a cognitive assessment tool for the cognitive mapping ability. Leitner et al [221] implemented three interactive prototypes to be used for rehabilitation exercises for the fields of visual impairments, visual and intellectual perception problems and training of fine motor skills and to define guidelines for tangible systems in rehabilitation domain. Rybarczyk et Fonseca [222] describe a TUI to be used for spoken and written therapy in aphasic patients. The patient has to identify tagged objects, from a set, and then he has to put them on a table to be recognized by the TUI system. The goal is that, by the manipulation of physical objects, the patients can transfer the training exercises into activities of daily life.

3.9 Touch/Multi-touch

Touch/Multi-touch is an interaction modality that enables do detect contact of body parts (usually fingers) with a surface. The interface mechanism typically tracks the position of the contacts to recognize gestures. Additionally, the use of pressure information is present in some systems. Touch input is widely used in different areas: public information kiosks, automatic teller machines, palmtop computers, portable computers. Touch input devices (touch screens, touch pads, tablets) can have a display or just an input tablet and detect touch position. Many devices also detect the amount of pressure used when touching (pressure sensitive interaction technologies).

Although most current commercially available touch screens, due to technical restrictions, enable only the tracking of a single point of the device, the multi-touch technology has evolved in recent years. Latest developments lead to multi-touch devices and systems able to detect, track and recognize several touch points and gestures at the same time. It includes software to interpret position and pressure of each touch point, allowing gestures and interactions with multiple fingers to be captured and enabling a more intuitive interaction [223].

Interactive surfaces and multi-touch tabletops have become very popular, providing highly interactive and immersive experiences and potentiating natural forms of interaction by enabling the user to directly touch and manipulate data on the screen without using any intermediary device. The term "Surface Computing" has emerged to refer to these technologies, aiming to replace the traditional graphic user interface elements with objects more intuitive that make part of user's everyday life and trying to mimic the familiar experience of everyday object manipulation through a touch-screen, instead of using the traditional mouse and keyboard.

An example of a commercial off-the-shelf multi-touch product is the Microsoft Surface table by Microsoft [224] that is considered the state of the art in surface computing [225]. Another example is the Diamond Touch, a technology for creating touch-input devices which allows simultaneous users and very intuitive forms of interaction, and requiring a projector to be mounted on the ceiling. However, these commercial platforms provide ergonomic interfaces and versatile programming environments at a relatively high cost [225].

The abilities of these multi-touch technologies contribute to make them more attractive to users and enhance the patients motivation, promoting its use in rehabilitation activities [218]. Multi-touch screens are also considered motivating environments for executing cognitive training games, promoting its use in cognitive rehabilitation [226]. Additionally, the immersion provided contributes to diminish the pain and discomfort felt by the patients [218]. Some multi-touch devices provide even a multi-user interaction.

Applications using these technologies can range from remote interface control, music composition, data organization, and rehabilitation. In [218], the authors developed a multi-touch system - AIR Touch, to be used in rehabilitation. The system uses an already available multi-touch surface, an open source software library (the openFrameworks) to modify the tabletop touch sensivity and a suite of five motor-based rehabilitation activities. These activities were designed to replicate real-world activities or provide alternatives to existing activities (such as to trace overtop a pattern on the surface) and enables to record the users' performance, allowing therapists to tailor activities according to patient needs. In [226], the multi-touch system was not developed specifically for rehabilitation but for cognitive training in promoting autonomy and independency of elderly users. In Theodoreli et al. [225], the authors develop a low-cost multi-touch surface platform with several games for elderly cognitive training, and using a robust visual finger tracking algorithm. In [180] an adaptation of the Microsoft Surface Table [224] is reported, made by researchers at the Spaulding Rehabilitation Hospital and the Harvard School of Engineering and Applied Sciences, to help children with CP to get a more engaging therapy. The table is programmed with custom games designed around specific goals such as movement, stretching, range-of-motion, use of both or arms together and enhanced visual skills.

3.10 Facial Expression Recognition

Facial expressions recognition systems play a key role in HCI and natural user interfaces and in Serious Games in particular. The user facial expression gives a measure of his satisfaction or experience in the game and thus the level of interaction or experiences in the game can be adapted to that measure [227, 228].

A human face can express not only his cognitive activity, intention, personality and psychopathology, but also his emotions [229]. Facial expression recognition plays therefore a very important for emotions or affects detection. It concerns with the identification of the affective states (happiness, sadness, disgustful, etc.) of humans [230]. Paul Ekman [231] has identified six universal emotions derived from facial expressions: fear, disgust, anger, sadness, surprise and joy. An automatic facial expression recognition system involves, in general, three main steps [231, 232]: face detection and extraction, facial feature extraction and facial expression classification. First, the faces are extracted from the input (static images or video inputs). Then, facial features are extracted from these faces, and finally, the resulting information of facial feature is analyzed in order to recognize the affective state of the user.

Automatic expression recognition can be very important for applications that require a good appreciation of the emotional state of users, such as in games, robotic, virtual reality, behavioral science, medicine and rehabilitation [228].

In [231], the authors present a rehabilitation serious game, developed for the PlayMancer European project [70], that includes an emotions/affects detection that is based on facial expressions recognition. The serious game is used in two rehabilitation scenarios: treatment of behavior and mental disorders and chronic pain rehabilitation and it combines different modalities of input: facial expressions recognition, speech recognition and bio-signals.

Other problems related to facial expressions recognition are for example: face detection, face localization, face recognition and facial feature detection [230]. In facial feature detection, the goal is to detect the presence and location of features, such as eyes, eyebrow, mouth, lips, nose, nostrils, ears, etc., assuming that there is only one face in an image [230]. However, the first step in any automated solution that solves the referred problems is to detect all regions in the scene (background) containing a human face [230, 233].

Most of the works on facial expression recognition are based on static images or dynamic image sequences (video inputs)[231, 232, 234, 235], where the approaches based on image sequences have shown to be more accurate and robust than the former ones [234].

3.10.1 Face Detection

Face detection consists in, given an arbitrary image, determine whether or not faces are present in the image and, if present, return the localization of the image and the extent of the face region [230]. There are however some problems associated that make face detection a challenge task [230]. For instance, faces can vary in scale, location, orientation (up-right, rotated), and pose (frontal, profile). Additionally, occlusion, lighting conditions and facial expression also change the overall appearance of faces.

Facial Recognition systems can operate on static images, where this procedure is referred to face localization [232]. If the system operates on facial image sequences (videos), the process is referred as face tracking [232].

Among the techniques for face detection, there are three groups that can be distinguished: an holistic representation, where the face can be represented as a whole unit, an analytic representation, where the face can be represented as a set of features and an hybrid approach where a combination of the previous is used [229, 232]. The face representation and the input images types determine the choice of mechanisms for an automatic extraction of facial features [232].

A detailed survey of approaches to face detection is given by Yang et al. [230]. According to the authors, existing techniques to detect faces from a single intensity or colour image can be classified in four main categories: knowledge-based methods, feature invariant approaches, template matching methods and appearance-based methods. In knowledge based approaches, rules are used that store human knowledge of what constitutes a typical face. These rules capture the relationships between facial features. These methods are mainly for face localization. In feature invariant approaches, also used mainly for face localization, the goal is to find structural features that are invariant even when the viewpoint, the lighting conditions and the pose vary. Then, these features are used to locate faces. Template matching methods have been used for both face localization and detection and use several standard patterns of a face, stored to describe the whole face or the facial features separately and compute the correlations between an input image and the stored patterns. In appearance-based methods, designed mainly for face detection, the models (or templates) are learned from a set of training images to capture the representative variability of facial appearance and then the resulting learned models are used for the face detection.

3.10.2 Facial Features Extraction

In facial features extraction, the goal is to extract facial expression information from the observed facial image or image sequence [232]. After the face has been located in the image or video frame, it can be analysed in terms of facial action occurrence.

Facial expression recognition systems can be distinguished based on type of features they use to describe facial expressions: geometric features, appearance features and a combination of the two [231, 234, 236]. Geometric features represent the shape of the several components of the face (eyes, nose, mouth, lips, etc.) and the locations of these feature points (corners of the eyes, nose, mouth, lips, etc.) and thus measure the displacements of certain parts of the face such as brows and mouth corners. To represent the face geometry, these geometric features are concatenated by feature vectors [234, 236]. In image sequences, a typical geometric feature extraction consists in automatically detect the approximate location of facial feature points in the initial frame, then adjust the points manually, and finally track changes of all points in the next frame [234]. These methods typically require accurate and reliable facial feature detection and tracking[236].

Appearance features describe the changes in face skin when a particular facial action is performed: furrows, bulges, wrinkles, etc. To extract appearance changes of the face, image filters, such as Gabor wavelets are applied to the whole face or to specific face regions [236].

Both geometric and appearance feature-based approaches have their own advantages and some authors suggest that hybrid approaches, combining both geometric and appearance features, can achieve better results for some facial expressions [231]. Huang et al. [234] present an approach that uses dynamic image sequences and combines geometric and appearance features.

Problems that can be associated with this face decomposition task are e.g. occlusions and occurrences of facial hair or glasses [237]. Detailed descriptions of the state of the art on automatic facial recognition can be found in [238, 239].

3.10.3 Expression Recognition

The classification of the expressions is performed by a classifier, often consisting of a model of pattern distribution, associated with a decision procedure. Besides facial feature representation, the classifier design is another important issue in an automatic facial expression recognition system. Most of the approaches use only one classifier [234].

The input classifier is the set of features extracted from face region in the previous stage. These set of features is formed to describe the facial expression, being classified into a predefined set of facial actions or to emotion related expressions [240]. The training set should have labelled data so that the classifier can assign a particular class label to the input image [241].

Facial expressions can be described at different levels [236]. For the description of the facial expressions, the majority of facial recognition systems use the Facial Action Coding System (FACS) model introduced by Ekman and Friesen [229, 235, 236]. The FACS model is a human observer based system used to capture subtle variations in facial expressions. Facial expressions are decomposed into one or more Action Units (AU). The system describes expressions using 44 AUs which are related to the contractions of specific facial muscles. Some examples of action units are showed in Figure 50.

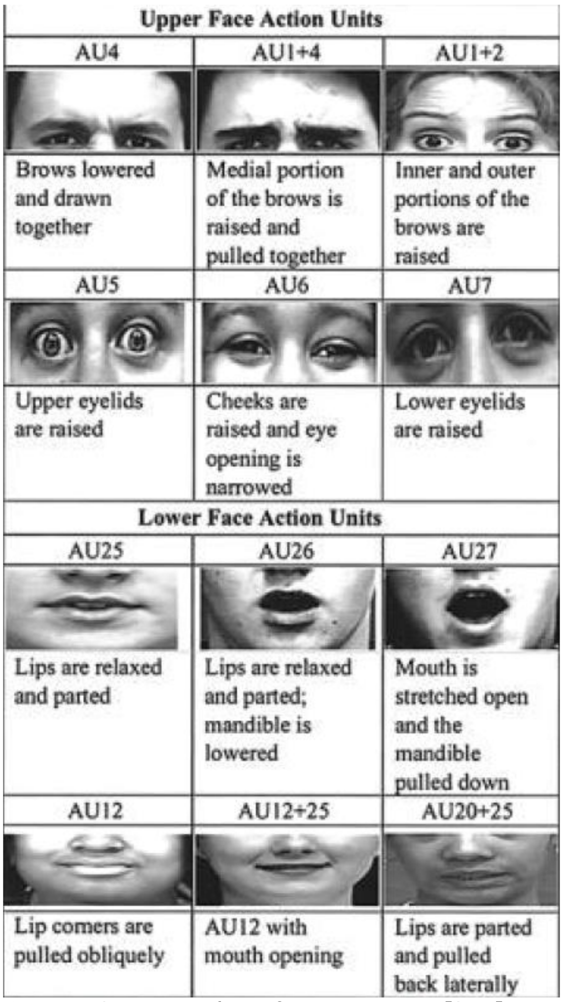


Figure 50 - Examples of Action Units [241]

Other commonly used facial expressions classification is based on a set of prototypic emotional expressions defined by Ekman [229] that are universal for people of different nations and cultures and that include disgust, fear, joy, surprise, sadness and anger [236]. These emotional expressions are presented in Figure 51.

Figure 51 - Six universal emotions [241].

Different machine learning techniques for the classification task can be used e.g. Artificial Neural Networks, Hidden Markov Models, K-Nearest Neighbours, Support Vector Machines, Expert Systems with rule based classifier, Bayesian Networks or Boosting Techniques (Adaboost, Gentleboost) [241].

Two main approaches in affect recognition systems can be distinguished [231]: spatial based and spatio-temporal based. In the first approach, spatial information of the extracted facial features in one frame is processed in order to recognize the affect. Bayesian network, and support vector machines are used in these approaches to recognize facial emotions [231]. Spatio-temporal approaches use the temporal information of the images sequence to recognize facial emotions. Hidden Markov Models and rule-based classifiers can be used in these approaches [231].

Most of the approaches use only one classifier. However, studies have shown that the combination of several classifiers will lead to an improvement in the classification performance [234]. Since each classifier introduces errors on a different region of the input space, several classifiers can supplement each other. Huang et al. [234] present an approach that uses dynamic image sequences with fusion of multiple classifiers (support vector machines, boosting, Fisher discriminant classifier) to improve the accuracy of the expression classification. Tests are made to evaluate the approach performance.

The approaches described in the literature are generally presented by the categories of the output of the classification: whether retrieve an action units based classification (Figure 50) or emotion detection based classification (Figure 51).

3.10.4 Fusion of Facial Expression Recognition Modalities

In a system that combines different modalities of input, the inputs retrieved by each modality cannot be treated independently. Such a system should handle imperfect input data and fuse the input retrieved from different modalities using a training model. In order to fuse the different input modalities, most approaches use probabilistic models for training where previously observed data are used.

There are many affect recognition approaches in the literature that fuse different input modalities. Some approaches combine voice and visual modalities to fuse information from voice and face, and create a more reliable system. Others fuse information from bio-signals and voices. Moussa et al. [231] makes a fusion of face, audio and bio-sensors information for the affect recognition.

The fusion of affective states can be made at two distinguished levels [231]: feature level and decision level. In feature level, data is fused immediately after the extraction of the features. The feature vectors from each modality are fused and only one global classifier is used to classify the affective state, as illustrated in Figure 52.

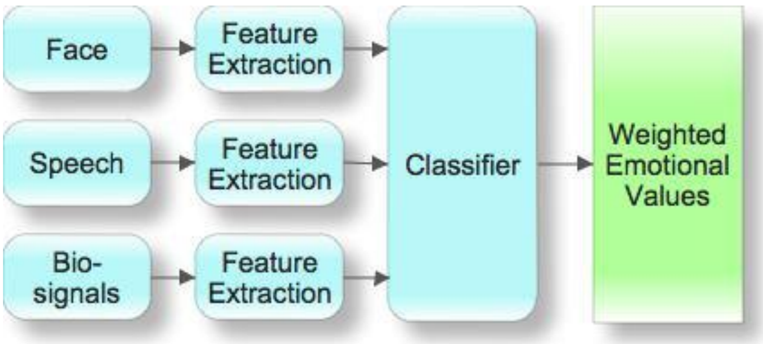


Figure 52 - Fusion of modalities at feature level [242].

In decision level, each modality has one local classifier that classifies the affective state and then the results from these local classifiers are fused at the decision layer, as illustrated in Figure 53.

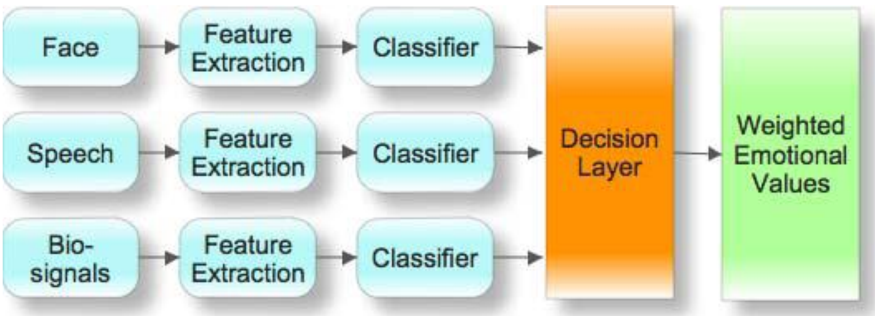


Figure 53 -PlayMancer Multimodal Emotion Fusion component – fusion at decision level [227, 231]

3.11 Eye Gaze Tracking

The use of the eyes as a way of interacting with computers has its origins in the analysis of gaze, that is, track to where a person is looking [243, 244]. Eye gaze tracking is the process of detecting and tracking the point of where the user is looking at – the point of gaze. The applications can be diverse: eye disease diagnosis, human behavior studies, social communication (emotions, dominance or submissiveness, attention or disinterest) [245] [246], etc. Eye gaze can offer several opportunities in HCI for many applications such as usability and interface research [247, 248] and games and interactive applications [249]. Eye gaze tracking can be used as an advanced input mechanism, driving the system interaction [250]. There are past studies that prove that this input modality can even be more efficient than the traditional input devices such as the mouse and keyboard [251].

The analysis of gaze allows us to establish a link between the user and that to which he is paying attention [252, 253]. Based on this principle, Dickie et al. [254] developed two applications: a video player that automatically pauses when you look away from the screen, and a reading application of digital books that advances the text as the user progresses in their reading. Using the same principle, a similar system could be implemented in the games so that they could present some sound when the user looks away. In a multimodal perspective, this technology can be combined, for example, with voice recognition, or forms of more traditional interaction, such was illustrated in the system described by Zhai et al. [251] where the mouse cursor displacement was achieved through the gaze, while the actions of click and selection continued to be performed with the mouse.

Developments in this area now allow tracking of eye movements, allowing people with movement difficulties, especially at the level of the upper limbs to interact with computers, for example using the eyes to move the mouse cursor and blink an eye as a way of clicking [252]. Although it is common to capture these signals by similar devices to video cameras, it is possible to integrate these systems into a pair of ordinary glasses [255].

Eye tracking devices (or eye trackers) can be used for people with and without disabilities and are widely used as assistive technology for disabled users who cannot control manually a mouse or a keyboard [247, 256, 257]. However, they can be also used in combination with the traditional manual input devices and thus can contribute to enhance the player experience for all people. Isoskoki et al.[249] give an extensive overview of gaze controlled games and discuss possible developments of gaze input for different game genres, for both disabled and able-bodied users.

Using eye movements in combination with other input devices can contribute also to make clearer what the user intentions are. For example, the use of speech in combination with eye gaze tracking can offer extra context when eye movements are vague, or vice-versa

[247]. Another multimodal approach is presented in [258], combining eye movements for special navigation and a BCI for activating commands, resulting in a hybrid BCI for touchless interaction.

Being attention and concentration one of the versed modalities in cognitive training, this technology could prove equally useful in this type of games, for example, to analyze which elements of the game users pay more attention.

Eye gaze tracking can be estimated using three main methods [245, 259, 260]. The most direct approach involves the fixation of a sensor to the eye. Other approach involves the extraction of the eye position from video images and others are based on Electro-oculography (EOG).

The first method consists in applying contact lenses to the eyes. The contact lens has an integrated mirror that allows the reflected light to be measured. Alternatively, small coils of wire can be embedded around the edge of the contact lens, as presented in Figure 54, and the eye movements can be measured by fluctuations in an electromagnetic field when the coil moves along with the eyes [247]. This method is used in medical and psychological research due to its advantages of high accuracy and high spatial and temporal resolution, allowing the detection of small types of eye movements. However, it has the disadvantage of being invasive, causing discomfort for the user.

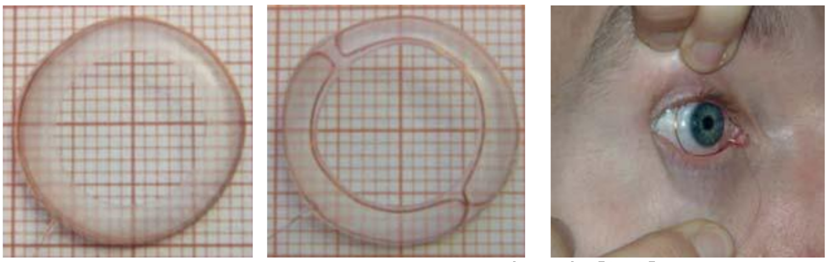


Figure 54 - Scleral search coils [259]

The second method involves the use of cameras to focus on one or both eyes and record and analyse their movements. This method can be divided in two main categories: head-mounted systems and non-intrusive systems [245]. Each of these can use ambient light or infrared or near infrared light.

Head-mounted systems use cameras (one, two, or three) with light emitting diodes to record several images, representing the reflections of emitted light in the eyes. If the light source is aligned with the camera optical axis then it is produced a “bright-pupil” effect similar to red eye effect in a photo, when using the flash. If the light source is offset from the camera optical axis then the pupil appears dark [245]. In the case of a bright pupil, light reflection occurs mostly in the camera direction, resulting in a greater contrast iris/pupil and allowing the video image easier to process. This technique is thus sensitive to pupil size and shows to be more accurate in a bright iris eye, since it produces a higher contrast. Additionally, it is more effective for darker environments, with less interference of infrared sources [245]. In some systems the user head has to be stable during eye tracking but other systems function remotely and automatically track the head during motion [245, 261]. In the case of a dark pupil, light is not reflected in the direction of optical path, resulting in a darker pupil. However, we can see in the image a small bright spot called the corneal reflection or glint, corresponding to the infrared source reflection. This technique can be used in outdoors (bright light environments) and it is not as sensitive to pupil size as the bright pupil technique. Eyelashes and shadows can however interfere with pupil detection, resulting in false positives [262]. Figure 55 presents an example of a head-mounted system.

Figure 55 - A head-mounted eye tracker system [246]

Non-intrusive systems can have some advantages relatively to head-mounted systems such as: should allow head movements in a more natural way, should be portable and should function in real time, adapted to a wide variety of eye shapes, glasses or contact lenses [245]. Figure 56 presents an image of a non-intrusive system.

Figure 56 - A non intrusive eye-tracking system [245].

In the third method, electro-oculography, electrodes are disposed on the skin near the user eyes, as presented in Figure 57, to measure small differences in the skin potential around the eye and estimate the eye position. This technique however is not comfortable for everyday use, since it requires a close contact of the electrodes to the user [245].

Figure 57 -Electro-oculography [259]

As an input modality, eye gaze tracking can take benefits from improvements on the technology (mainly from an increase in robustness of data capture) and from the fact that, due to the recently advances in eye tracker hardware and software, this technology is becoming more affordable, less invasive and easier to use.

There are some examples of the use of eye gaze tracking in rehabilitation domain [256, 257, 263]. In [263] the authors describe the design and development of an eye tracking-based system for the rehabilitation of a patient with the locked-in syndrome that uses a head-mounted camera to capture images of the patient's eye. A completely locked-in patient is an individual that lost his ability to communicate verbally and his motor control due to a paralysis of nearly all voluntary muscles, except for the eyes. In [256] the authors describe the use of a commercial infrared eye-tracking system in a case of cognitive rehabilitation for a patient with TBI and severe motor disturbances and cognitive impairment.

3.12 Fusion of Modalities

A multimodal HCI system responds to inputs in more than one modality or communication channel (e.g., speech, gesture, writing, among others). Thus, in a multimodal interface, we can have more than one modality and the system accepts many different inputs that are combined in a multiple and coordinated way. In each modality, we can although have more than one form of interaction. The visual modality, for instance, includes any form of interaction that can be interpreted visually, and the audio modality any form that is audible [113]. In terms of input devices, we can have modalities that are equivalent to human senses such as: cameras (sight), haptic sensors (touch), microphones (hearing). However, there are other input devices such as: keyboard, mouse, motion input and writing tablet that do not correspond directly to human senses.

In a multimodal interface a key issue is therefore the integration of information from different modalities. A correlation and synchronization of modalities will be necessary before the multimodal fusion and must be clearly analyzed [172].

Having alternated input modalities is a crucial aspect in computer games. The use of only a single device could limit accessibility, which is why the combination of multiple input and output modalities is an important objective [70]. People in rehabilitation can have disabilities that prevent them from using traditional techniques, such as mouse or keyboard, and for these, alternative means of interaction are very important. For example, users that cannot grasp objects with their hands cannot use e.g. the Wiimote to control a virtual environment on the screen. Other modalities of input should be considered to accommodate those users. On the other hand, the combination of several modalities can reduce noise and dissolve ambiguities that could exist in having only one modality, contributing to the increase of the robustness of the system [203].

Providing a flexible use of input modes and an increase in the user degrees of freedom, multimodal interfaces allow more interactions with the system, provide an enhanced, more immersive and realistic user experience and are perceived by the users as being more accessible and easier to use [123], and thus, more natural.

Users can communicate or interact with the machine by several forms that need to be interpreted by the machine. A machine interpretation of human behavior is very important in the interaction human-computer for achieving natural forms of interaction. Users can convey messages in the form of body gestures, facial signals, speech, and emotions, among others. Gestures recognition and emotion recognition play therefore an important role in natural user interfaces and both systems can have a multimodal nature.

In natural interaction approach, gestures can be considered the preferred way to interact with objects and to convey information, meaning, and intentions. Attributes like familiarity, intuitiveness, and naturalness can contribute to this fact. In computer games they can contribute to augment the player's interactive experience. Gestures recognition systems can have a multimodal nature since gestures can be translated in hand gestures or body positions and movements that control a virtual environment on the screen, being captured by cameras or by the use of data sense gloves, or they can be a sequence of finger positions and movements in a multi-touch table, or they can be face gestures.

Emotions have also a multimodal nature. They can be expressed through several modalities (and channels): verbally by the use of emotional vocabulary or by expressing several non-verbal cues such as facial expressions, voice intonation, postures, gestures, and physiological changes. The decoding of these cues is essential to interpret the correct message [228]. It is therefore necessary in a multimodal system to make a fusion of these different modalities to achieve a reliable (accurate) assessment.

Another key issue is that emotions detection plays an important role in affective computing for the development of engaging games and in adaptive interfaces. Affective computing is the area of HCI that studies the development of systems which identify emotional states and, based on that information decide the proper actions to execute, and systems that simulate human emotional states [228]. Emotion detection can be used to evaluate automatically the user experience in the game (or software), not only in entertainment, but also in serious games. The recognition of player emotions can be used to tailor the game responses, according to player's emotions. For instance, levels difficulty in games can be increased or diminished or reward structure can be changed, according with the state of interest of the player (interested or frustrated/bored). In adaptive interfaces, the system tries to adapt itself to the way the user experiences the interaction [203]. User experience can also be measured using several modalities of input, including biofeedback, information from voice, face and head. Brain signals contain information about user experience, along with other information measured from the body: bio signals as heart rate, body temperature, respiration, and muscle tension. The contribution of each modality to the final output of the recognition system should be weighted using a reliability measure. A good indication of the reliability of the various measures is important to obtain a reliable recognition system [203]. The information given by these multimodal measures is important to infer about the cognitive and affective state of the user and in the development of adaptive interfaces for games.

Multimodal interfaces emerged in the field of HCI in 1980 with the work of Richard Bolt: the application "Put-That-There" [264], using the traditional interaction mode which was graphical interfaces with keyboard and mouse. Since this seminal work, researchers strive to integrate more modalities, refining software and hardware and exploring the capabilities and limitations of multimodal interfaces. The trend in early multimodal systems was to have speech-based systems combined: hand gestures and speech [202], voice and gaze [188], speech and gaze [265]. Turk [266], Dumas et al. [267], present good surveys on multimodal interaction research. Multimodal interfaces using combinations of more input sensors in rehabilitation games have been growing. Examples of these solutions can be seen in seen in several works [116, 268-277]. Omelina [274] describes a serious game system for neuro-muscular rehabilitation that can operate with a large range of input sensors such as: keyboard, Kinect, accelerometers and balance boards. Badesa et al. [277] describes a robotic system that increases motivation of stroke patients by using multisensory data (skin temperature, pulse, etc) to adaptively change the complexity of the therapy tasks. Faria et al.[276] uses the concept of an intelligent wheelchair that is controlled using high-level commands in a multimodal interface that uses voice, facial expressions, head movements and joystick as the main input forms and users have the option to choose the input type that best fits their needs, thereby enabling them to increase their safety and comfort. Users can convey information also in the form of gestures Trigueiros et al. [278] use a gestures concept for a vision-based hand gesture recognition system that can be integrated in an HCI system [279-281].

3.13 Summary

We presented the major input modalities associated to the use of natural user interfaces. Our description focused in the technology main goals, main applications and its application in the rehabilitation domain.

The application of VR technology for the rehabilitation of cognitive and motor deficits has been growing in the last decade and stroke patients have been one of the main target populations for these new rehabilitation methods [6]. These VR based-methods can offer the patients to be part of immersive experiences that are engaging and rewarding for them. Additionally, several motion tracking devices have been introduced by the gaming industry, enabling the use of game consoles for home-based rehabilitation with some type of gesture based game play. Noticeable examples of the later are the Nintendo Wii with the Wiimote, PlayStation 2 EyeToy, PlayStation 3 Eye and Microsoft Kinect and PlayStation 3 Move systems. Modalities as speech recognition, facial expression recognition and touch input are also used in rehabilitation to become accessible by patients with several motor and cognitive impairments.

Chapter 4

Taxonomy for SGHR

4.1 Introduction

Serious Games can be seen from multiple perspectives (application area, users, interaction technologies, among others). To manage this variability in characteristics and concepts and to facilitate a comparison between the different prototypes (and their characteristics) that have been carried out and published in this area, a taxonomy is important. Additionally, it contributes to facilitate future literature reviews and searches in this area.

In this chapter, we present a taxonomy proposed for Serious Games in Health Rehabilitation (SGHR), based on a set of criteria that we found to be relevant to compare and classify SGHR. Next, we present a comparison of the reviewed games according to the proposed criteria, providing thus an application of the proposed taxonomy.

Following the classification of reviewed Serious Games, we present a study of the input modalities present in the reviewed rehabilitation serious games, providing thus a classification of Serious Games focused on the use of NUI.

As several authors have been adopting our taxonomy presented in [90] in the classification of their rehabilitation serious game prototypes, using all or some of the criteria of our taxonomy, we update our state of art in this area presenting a description of the context of their work and the criteria they adopt to describe their games. Some of these authors extended our taxonomy including some more relevant criteria. As several works, updates and innovations in game criteria have been researched since our first publication of the taxonomy in 2010, we developed an update to our first proposal and propose an extended taxonomy for Serious Games in Health Rehabilitation that is based on the published literature on this area.

Additionally, we intended to validate the interest and applicability of the proposed extended taxonomy for the classification and comparison of SGHR. For that purpose, we made a survey among experts in the area (serious game / video game design, interaction, health/ rehabilitation) and in related areas (informatics, computer graphics, and computer programming). We present and discuss the results of the conducted validation. In the analysis of the answers to the questionnaire, some of the participants made proposals concerning modifications to our extended taxonomy that we found useful to include in our final proposal. Because of that, we make some modifications to our extended proposal and we present an improved proposal for the extended taxonomy.

4.2 Proposed Taxonomy for SGHR

In chapter 2 we made a literature review on applications of serious games in rehabilitation. We identified a set of criteria to classify these applications. In section 4.2.1 we present and define the criteria we found relevant from literature review. Then we divided the applications reviewed according to these criteria.

4.2.1 Relevant Criteria

In this subsection we present our proposal [90, 282] of a classification schema towards a taxonomy based on a set of criteria that can be used for the design of expectable more effective rehabilitation games. This classification framework enables us to present a summary and a comparison of serious games for rehabilitation. Based on this classification, existing games could become more functional tools for the rehabilitation therapy, if modified in order to satisfy a large number of the identified classification criteria. Additionally, the defined criteria will enable us to comprehend the different rehabilitation scenarios that can be attained with the use of Serious Games.

Based on the literature reviewed we identify as important main criteria for the classification of Serious games in the rehabilitation area the following ones. These criteria can be associated to the rehabilitation process and to the game itself.

Application area

Application area is the domain application in which a game can be applied; although this domain can be very vast, we may consider however two main applications: cognitive rehabilitation (Cognitive) and physical/motor rehabilitation (Motor).

The primordial goal of Cognitive rehabilitation is the reduction of the deficiencies resulting from brain injuries. Cognitive rehabilitation is a process focused on the patient's reacquisition of the most independent or highest level of functioning. Cognition can be described as the process of thinking and awareness and includes mental faculties such as memory, attention and concentration, reasoning and problem solving, language, volition and judgment, amongst others. These faculties are very sensitive and are prone to influences from psychiatric conditions, neurological disease, medical conditions and head injuries [283]. The rehabilitation is based on goals adapted to the patient's current strengths and weaknesses. In TBI, a disruption of brain functioning occurs when a mechanical force causes damage to brain tissue, and cognition is frequently affected after that. As a result of a stroke, patients can suffer cognitive, visual and motor losses. In terms of cognitive functions, stroke survivors may have losses in memory, attention, concentration and speech.

Motor rehabilitation comprehends therapies for distinct medical conditions such as: stroke rehabilitation (upper and lower limb extremity training, spatial and perceptual-motor training), balance training [67, 284], acquired brain injury, wheelchair mobility, Parkinson's disease, orthopedic rehabilitation, functional activities of daily living training, and telerehabilitation [284].

Adaptability

Adaptability (Yes/No) is the system capability to adapt dynamically game difficulty or challenge, according to the patient performance in the game. At the start of a new game, and because the player is not familiar with the game, he usually wants a low level of challenge. Many games use levels to compose difficulty. Other games may not have identifiable levels, but indicate that the player has achieved an adequate level of comprehension and skills, by increasing challenge as specific points in the game are reached. In other games player actions are recorded, analyzed, and game elements may change dynamically to maintain an adequate level of challenge, making the game easier or harder to play, according to the player abilities.

Performance Feedback

Performance Feedback (Yes/No) is related with the system capability to transmit to the patient the results of the interaction. This feature gives the patient a measure of his progress in achieving goals, or in his skills over time. It can be used to identify correct or incorrect actions or responses, necessary to give the patient a visible meaning of the result of his interaction with the system and can have multiples modalities (aural, visual and haptic).

Progress monitoring

Progress monitoring is the functionality provided by the system to allow the monitoring, analysis and management of the progress achieved by patients using the system in the context of a prescribed therapy.

Game portability

Game portability is related with the capability of the system to be used at home, or at a hospital or clinic.

Interaction technology

Interaction Technology is the technology used by the patient to interact with the system. This can vary from the traditional methods using a mouse or keyboard process to VR based methods. For instance, in VR, interface devices that can be used are: visual interfaces that include head-mounted displays (HMDs) and desktop monitors; haptic interfaces like data gloves; and motion tracking devices. With these devices patients become able to interact with virtual objects in the environment in real-time using several sensory modalities (vision, haptics, and audition). In telerehabilitation the devices used are webcams, videophones, videoconferencing over phone lines, and web pages with rich Internet applications. These modalities of interaction can be present individually or in a combined form.

Game graphical interface

Game graphical interface is the dimensionality of the game virtual environment interface used in the game. It can be two-dimensional (2D) or three-dimensional (3D).

Number of Players

Number of players is the number of patients (users) playing the game: single player (single) or multiplayer (multi).

Competitive/Collaborative

Indicates if the game is based on competitive and/or collaborative tasks, when the number of players is greater than one.

Game genre

The games genre can vary in relation with the technology used. Examples found include: games to evaluate the movement (catch, reach and grasp) and games that are simulations, strategy, or a combination of several (assorted).

Figure 58 presents our proposed taxonomy of SGHR.

4.2.2 Comparing reviewed games according to the proposed criteria

In chapter 2, we presented in detail a review of more relevant works found in literature, and here we present a table (Table 3) that summarizes the reviewed serious games applications for rehabilitation in respect to the proposed set of classification criteria. The table allows to more easily compare their characteristics, according to these criteria.

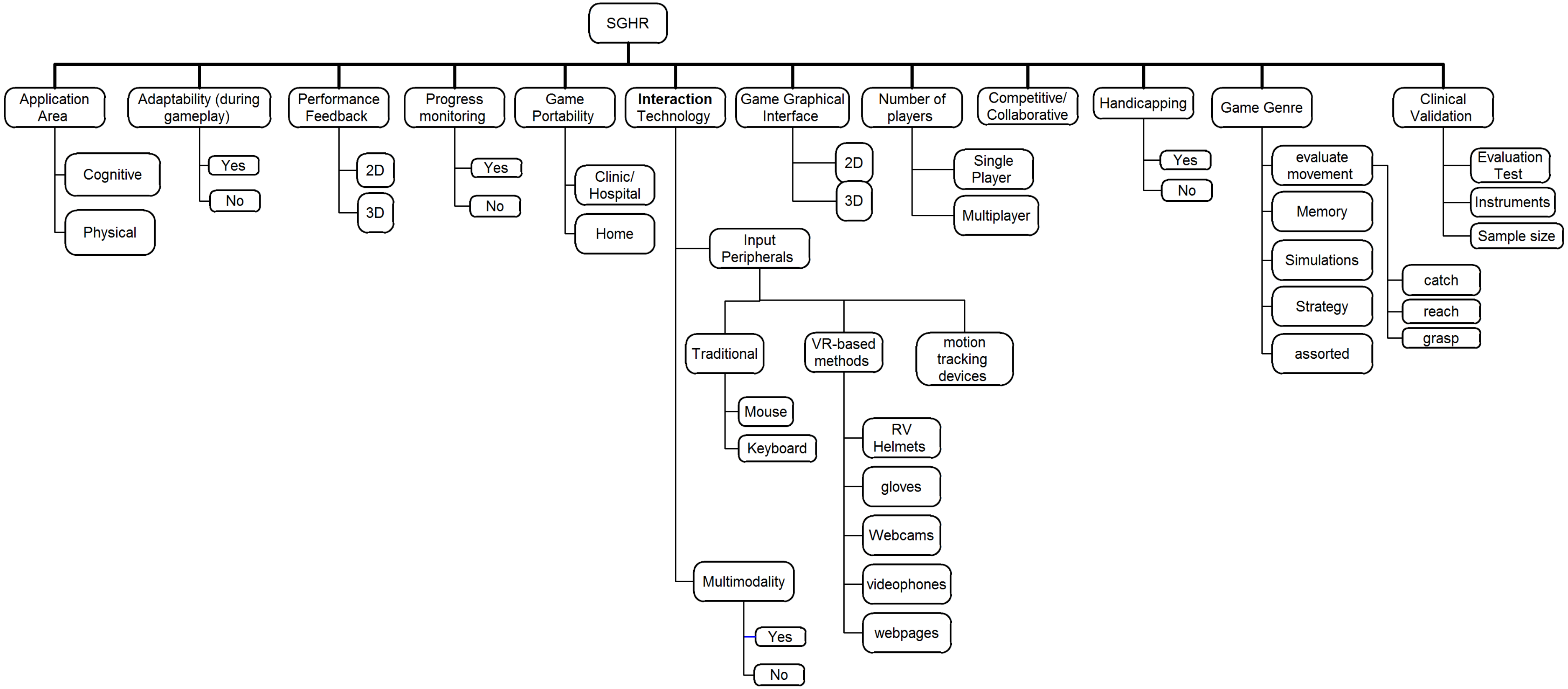


Figure 58 - Our Proposed Taxonomy of SGHR

Table 3 - Classification and Comparison of the reviewed Rehabilitation Serious Games.

Rehabilitation Serious Games	Rehabilitation Criteria					Game Criteria				Evaluation
	Application Area	Adaptability	Progress Monitoring	Performance Feedback	Portability	Interaction Technology	Game Interface	Competitive/ Collaborative	Game Genre	Sample size
Betker et al. (2007, 2011) [67]	Motor	Yes	Yes	Yes	Home	COP position + Pressure mat	2D	None	Memory+ simulation	3; 27
Ma et Bechkoum (2008) [69]	Motor	Yes	Yes	Yes	Clinic	Motion Tracking + HMD	3D	None	Simulation	8
Conconi et al. (2008) [70]	Cognitive	Yes	Yes	Yes	Clinic	Speech + Touch+ Motion Tracking + Biosensors	3D	None	Strategy	--
Battocchi et al. (2008) [86]	Motor	--	--	--	Clinic	Multi-touch table	2D	Collab.	Puzzle	4
Caglio et al. (2009) [71]	Cognitive	No	No	--	Clinic	keyboard	3D	None	Simulation	1
Cameirão et al. (2009) [72]	Motor and cognitive	Yes	Yes	Yes	Clinic/ Home	Vision-based Motion Tracking + 2 data gloves	3D	None	--	6; 14
Burke et al. (2009) [6]	Motor	Yes	Yes	Yes	Home	Motion Tracking	2D	None	Simulation	
Ryan et al. (2009) [76]	Motor	--	--	--	--	Wiimote Wii Balance	2D	None	Maze	--
Brown et al. (2009) [77]	Motor	--	Yes	Yes	Clinic	Wiimote + 4 diodes + data glove	3D	None	Assorted	--
Vanacken et al. (2010) [85]	Motor	--	--	--	Clinic	Force-feedback device + wiimote	2D	Collab.	Simulation	--
Alankus et al. (2010) [62]	Motor	Yes	No	Yes	Clinic	Wii Remotes + webcam	2D	Comp. and Collab.	Memory + Simulation	4
Burke et al. (2010) [9]	Motor	Yes	Yes	Yes	Clinic	Webcam + AR markers	3D	None	Simulation	--
Saposnik et al. (2010) [78]	Motor	--	--	--	Clinic	Wii Remote	3D	None	Simulation	22
Anderson et al. (2010) [87]	Motor	--	Yes	Yes	Clinic/ Home	Wii Remote + Wii Balance Board	3D	Comp. and Collab.	Simulation	--
Madeira et al. (2011) [285]	Cognitive	Yes	Yes	Yes	Home/ clinic	Motion tracking + RFID + biofeedback + situated ambient displays + tablets on wheelchairs + mobile phones + webcams	2D	Comp. and Collab.	Assorted (memory and mahjong based games)	--
Ballester et al. (2012) [88]	Motor and cognitive	Yes	Yes	Yes	Clinic/ Home	Vision-based Motion Tracking + 2 key-gloves	3D	Comp.	Memory+ Simulation	6
Bermudez i Badia et al. (2012) [79]	Motor and cognitive	Yes	Yes	Yes	Home	Vision-based Motion Tracking + 2 mice	3D	None	Simulation	10
Cameirão et al. (2012) [286]	Motor and cognitive	Yes	Yes	Yes	Clinic/ Home	Vision-based Tracking + 2 data gloves+ force-feedback mechanical arm+ exoskeleton	3D	None	Simulation	44
Vourvopoulos et al. (2013) [82]	Motor and cognitive	Yes	Yes	Yes	Home	EEG+EMG+Kinect+ robotic orthosis	3D	None	Simulation	3
Fikar et al. (2013) [287]	Motor	Yes	Yes	Yes	Home	Kinect	3D	None	Simulation	--
Baranyi et al. (2013) [288]	Motor	Yes	Yes	Yes	Home/ clinic	Balance board	2D	None	Maze	--
Davies et al. (2014) [289]	Motor	Yes	Yes	Yes	Home	Kinect	2D	None	Simulation, catch	5

From the comprehensive literature review presented about SGHR in the previous chapter and summarized at Table 3 we conclude that the adoption of Serious Games as rehabilitation tools is very recent in general.

Most of these games present simple interfaces and traditional forms of interaction. More natural user interfaces are exploited in some recent games [6, 9, 62, 69, 70, 72, 76, 85, 86], but are poorly evaluated in terms of the rehabilitation process.

Additionally, few games present or study a social dimension. Most of the games are designed as for single user activities. Recently, there are reports on multiplayer games [62, 85-87], where the collaboration and competitiveness facility exists, but the evaluations done are inexistent (yet planned for future studies), or conducted with a very small number of patients. Nevertheless, all of these works refer to progress monitoring, performance feedback and adaptability.

A significant number of the reported research refers to prototypes and to games in early stages of development and testing. Furthermore, there are few examples where a significant sample of real patients was used to validate the proposed approaches. Consequently, definitive conclusions about their effectiveness are hard to take and must be validated by further research.

4.3 Classification for SGHR based on NUI

As interaction modality was identified as an important criterion for the classification of Rehabilitation Serious Games, in this section, we present a classification of the rehabilitation serious games reviewed in chapter 2 based on the natural user interfaces used in these games. Therefore in Table 4 we present the input modalities present in rehabilitation serious games reviewed in Table 3. As most rehabilitation works found use motion detection as input modality we present a separate table -Table 5, for summarizing relevant works using this modality.

Table 6 summarizes relevant rehabilitation works found in the literature that use other natural input modalities than motion detection. The "--" means that this feature is not mentioned in the reviewed paper.

From a deep analysis of the summarized features presented at Table 4 to Table 6 and from the NUI literature review, we were able to conclude that the use of NUI in the rehabilitation domain is still in its infancy. Until nowadays, most used natural modalities are motion detection, due mostly by the gestures game play implemented by major game consoles in the entertainment area.

Recent technological developments encourage us to study and propose the adoption of more input modalities, making the games more adaptable to different users' needs and giving to them, in conjunction with a better user experience, a more effective rehabilitation.

Table 4 - Review of Rehabilitation Serious Games of Table 3 using natural forms of interaction

Rehabilitation Serious Games	Sensors/Actuators						Detection Type								Social Dimension	Evaluation Test
	Force feedback	Accelerometer	Infrared sensor	Webcam	Microphone	Biosensors	Motion detection	Pressure	Touch/ Multi-Touch input	TUI	Voice/Speech detection	Biofeedback	Facial Expression detection	Gaze detection	Competitive/ Collaborative	Sample size
Betker et al., 2007 [67]	X						X	X							None	3
Ma et Bechkoum, 2008 [69]							X								None	8
Conconi et al., 2008 [70]					X		X				X	X	X		None	--
Battochi et al., 2008 [86]									X						Collaborative	4
Cameirão et al., 2009 [72]							X								None	6
Burke et al., 2009 [6]				X			X								None	3
Ryan et al., 2009 [76]	X	X					X								None	--
Brown et al., 2009 [77]			X				X								None	--
Vanacken et al., 2010 [85]	X	X	X				X								Collaborative	--
Alankus et al., 2010 [62]		X	X	X											Both	4
Burke et al., 2010 [9]				X			X								None	--
Saposnik et al., 2010 [78]		X	X				X								None	22
Anderson et al., 2010 [87]		X	X				X								Both	--
Spina et al., 2013 [171]		X					X								None	7
Chang et al., 2011 [183]		X	X				X								None	2
Golomb et al., 2010 [166]			X				X								None	3
Annett et al., 2009 [218]										X					Collaborative	--
Theodoreli et al., 2010 [225]									X						None	--
Trojano et al. 2010[256, 257]														X	None	1
Ballester et al., 2012 [88]				X			X								Competitive	6
Cameirão et al., 2012 [286]	X	X		X			X								None	44
Vourvopoulos et al. (2013)[82]				X		X	X								None	3

Table 5 - Review of Natural User Interfaces in Rehabilitation (motion detection only)

Rehabilitation Serious Games	Input Devices						Motion Detection Type		
	Wiimote	Wii Balance Board	Data Gloves	Mobile Phones	PS Eye/Move	Microsoft Kinect	Non optical - Inertial based	Optical with Markers	Optical without Markers
Deutsch et al., 2008 [157]	X						X		
Decker et al., 2009 [290]	X						X		
Joo et al, 2010 [158]	X						X		
Saposnik et al., 2010 [78]	X						X		
Ryan et al., 2009 [76]		X					X		
Sugarman et al., 2009 [291]		X					X		
Deutsch et al., 2009 [292]		X					X		
Anderson et al.,2010 [87]		X					X		
Gil-Gómez et al.,2011 [293]		X					X		
Morrow et al., 2006 [164]			X				X		
Golomb et al., 2010 [166]			X				X		
Walters et al., 2010 [170]				X			X		
Rand et al.,2004 [173]					X			X	
Flynn et al., 2007 [174]					X			X	
Huber et al., 2008 [294]					X			X	
Orendorff, 2011 [295]						X			X
Chang et al., 2011 [183]						X			X

Table 6 - Review of Natural User Interfaces in Rehabilitation *

	Input Devices							Detection Type							
Rehabilitation Serious Games	Microphone	Force	Touch	Image/ Video	RFID & Computer Vision	EEG device	Other bio-sensors	Touch/ Multi-Touch	Voice/ Speech	Haptics	Tangible Surfaces	Biofeedback	BCI	Facial Expression	Eye Tracking
Annett et al.,2009 [296]			X					X							
Facal et al.,2009 [226]			X					X							
Theodoreli et al.,2010 [297]			X					X							
Microsoft, 2011 [298]			X					X							
Conconi et al, 2008 [70]	X			X			X		X			X		X	
Moussa et al.,2009 [299]	X			X			X		X			X		X	
Bardorfer et al., 2001 [215]		X								X					
Jadhav et al., 2004 [213]		X								X					
Pridmore et al., 2007 [155]					X						X				
Leitner et al., 2007 [157]					X						X				
Sharlin et al., 2009 [156]					X						X				
Rybarczyk et Fonseca, 2011 [158]					X						X				
Yoh et al., 2010 [300]						X							X		
Wang et al., 2011 [301]						X							X		
Abu-Faraj et al., 2006 [263]				X											X
Trojano et al., 2009 [256]				X											X

* Except Motion detection modalities which are presented in Table 5

4.4 Adoption of our Proposed Taxonomy of SGHR

Several authors adopted our taxonomy for Cognitive and Physical Rehabilitation Serious Games presented in [90] for designing their rehabilitation serious game prototypes, considering all or some of the criteria we found as relevant for designing games in this area (described in section 4.2.1). Examples of these are Assad et al. [302], Fikar et al. [287], Menezes et al. [303], Bruno et al. [304], Ferracani et al. [305], Jaume-i-Capó et al. [306]. Some authors extended our taxonomy including some more criteria such as Marin et al. [307], Madeira et al. [285], Wattanasoontorn et al. [308], Baranyi et al. [288], Davies et al. [289], Tavares et al. [309], Cancela et al. [310], Hao et al.[311], Barret et al. [312] and De Lope et al. [313]. Next, we present, for each author referred above, a description of the criteria they use for designing the serious games and at what extent they use the same criteria we proposed.

4.4.1 Studies using our taxonomy

4.4.1.1 Assad et al (2011)

Assad et al. [302] apply and adopt our proposed taxonomy for describing their game system named as "WuppDi!" which is composed of five motion-based games for the rehabilitation of Parkinson's disease patients. The games are implemented using Microsoft XNA Game Studio 4.0 and use as input a webcam. The input processing is done with and without colored markers and is implemented using the OpenCV3 computer vision library. Marker input is based on a color tracking approach that is able to distinguish yellow and red markers. Markerless input is based on detecting movements of the player by computing the difference between subsequent frames of the webcam capture. The webcam image or the binarized image difference is shown in the background during play in order to give the player spatial feedback. The authors conducted a field test that showed a very positive motivational effect among the majority of the patients.

4.4.1.2 Elaklouk et al. (2012)

Elaklouk et al. [314] adopt our interaction technology criterion as an important game design principle for brain damage rehabilitation, among other three criteria: meaningful play, challenge and portability. The authors consider these criteria critical for games to be accepted and effective in rehabilitation and present several game prototypes developed based on these design principles.

4.4.1.3 Fikar et al. (2013)

Fikar et al. [287], adopted our proposed taxonomy criteria [90] in the design of a serious game proposed in the context of subacromial impingement syndrome (SIS) that can be applied in a home environment, in addition to conservative therapy or rehabilitation after surgical treatment. SIS is a cause for shoulder pain, influencing the daily lives of the person concerned, causing pain in the shoulder, for example when combing hair, and may lead to loss of strength. It can be induced by several factors like continuous overexertion by working overhead with the upper limbs and can be caused by pathological factors, which lead to a narrowing of the space between the acromion and the head of the humerus, leading to pain by impingement of the rotator cuff tendons. The serious game aims to improve mobility and strength of the shoulder area through several options of exercises embedded into the flow of game play and uses motion tracking for input through the Microsoft Kinect, being this a low-cost input-output device suitable for home training. The exercises are integrated into meaningful play for the patient. The authors plan to evaluate the game towards usability, emotional engagement and efficacy in a future study with patients.

4.4.1.4 Menezes et al. (2014)

Menezes et al. [303] present a comparative analysis of six selected studies of serious games for motor rehabilitation using our proposed taxonomy. The authors developed a game system for motor rehabilitation that uses kinect as input system and describe the features developed in their motor rehabilitation game system using our proposed criteria.

4.4.1.5 Bruno et al. (2014)

Bruno et al. [304] consider our taxonomy criteria to classify serious games for the rehabilitation of people of age 50 and above. They conduct a literature revision and a questionnaire to 23 health professionals of the Valparaiso region about the requisites for a serious game that could help people at age 50 and above to develop appropriate activities. The questionnaire focused the aspects the practitioners find to be more important in activities involving this group of people and better performed by this group of people. These aspects were related with types of interventions, motor skills, performance skills, communication/interaction skills, process skills, context, performance patterns, and usage of computer games in the interventions they made.

4.4.1.6 Ferracani et al. (2014)

Ferracani et al. [305] describe a work in progress of a serious game system to train professionals in surgery to carry out efficiently the Surgical Security Checklist (SSC) introduced by the World Health Organization in 2009. The system is set in an immersive virtual environment and adopts natural interaction via gestures and voice using the kinect sensor. The simulation involves up to three trainees, each of them with a specific associated role (surgeon, anesthesiologist and the nurse). The authors described the developed system using the taxonomy proposed by Wattanasoontorn et al. [308, 315], which is an extension of our proposed classification system.

4.4.1.7 Jaume-i-Capó et al. (2014)

Jaume-i-Capó et al. [306] developed a serious game for balance rehabilitation of CP patients, which have abandoned the therapy in previous years due to demotivation. The serious game aimed to improve coordination and trunk control, stimulation of cognitive and communicative aspects, and improve their activity of Activities of Daily Living in the rehabilitation center. For the development of the serious game they followed a set of features they identified as desirable to create a motivation tool in rehabilitation programs that includes some of the criteria of our proposed taxonomy such as: interaction technology, feedback, adaptability, monitoring and clinical evaluation.

4.4.2 Studies that use and extend our taxonomy

4.4.2.1 Marin et al (2011)

Marin et al. [307] present a classification scheme of serious games for improving the physical health of the elderly, considering mainly a review of research projects representing working prototypes and that incorporate user-centered design for the elderly.

This classification is used for the design of serious games for physical and cognitive rehabilitation of older adults that suffered stroke and games for falls prevention and balance training and for this they adopted our taxonomy [90], complemented and extended it. They adopted and complemented mainly our criteria related with the rehabilitation process (such as progress monitoring, performance feedback, and portability) and extended our taxonomy with other criteria such as:

- Audience: elderly;
- Goal: is to improve physical health in what concerns upper limbs, lower limbs, balance;

- Measurement: any of these: range of motion, user movements and trajectories, high scores, game results;
- Special age appropriate features: large visual instructions, audio assistance, mechanisms to dynamically adapt challenge, monitored by the occupation therapist.

In what concerns our interaction technology criterion, they considered it decomposed in two criteria:

- Interaction form: any of these: Shifting weight, Wearing Sensor (Image Recognition), Stepping on Surfaces, Touching Surfaces, and Grasping Objects;
- Interaction technology: any of these: commercial platforms: Wii, PS, Xbox, Kinect; PC Games; Robot; Balance Board; commercial remote controller; Camera / WebCam; Dancing Pad; MultiTouch Tabletop.

4.4.2.2 Madeira et al.(2011)

To define a model of principles and criteria to the design of therapeutic serious games (theragames) for aphasia rehabilitation, Madeira et al. [285] adopted our taxonomy [90], considering our set of criteria, and extended it, considering also a few more criteria.

The main causes of aphasia are mostly cerebral tumors, stroke, head injury and degenerative diseases. Patients with aphasia are characterized by a total or partial loss of language codification, compression, decodification and production. According to the authors, the development of games should have in consideration both patients' specificities and practitioners needs, with a high level of acceptance by both. In addition, the games should be designed taking into account preferably elements pervasively embedded in the environment (avoiding the patients to carry out the devices for the game therapy wherever they go) and the interfaces of the games should be simple, easy to understand, user-friendly, persuasive and informative. In addition, the development of the games should reuse and adapt the general architecture proposed by the authors. In this sense, the serious games are to be used in a pervasive healthcare assistive environment that integrates smart objects such as wheelchairs.

The authors present an architecture for the design of the pervasive assistive environment to be reused and adapted by the developed games. They describe the main game which is in development and a prototype game (AftheraGame) already developed that is included in the main game as a sub-game. The main game is based in pervasive computing and augmented reality (AR) and applies VR concepts. It uses the location and movement of the user's wheelchair as input for the gameplay. The paths, the virtual objects' positions, and the activities spots are marked on the floor using RFID tags and those are tracked and identified by the wheelchair's RFID reader.

Personalization and adaptation of levels difficulty is based on patients measured vital signals (and scoring history). It will have an additional interface designed for the ambient displays, where the therapist will visualize the general map in the public display, to follow the global action, contributing to a multiplayer therapy with collaboration and competition settings. The game will have three gameplay scenarios where the patients would have to pick-up virtual objects at specific positions of the map, through the physical movement of the wheelchair, passing on their corresponding physical, or they would to have complete diverse physical circuits within time limits, or they would have to move in the wheelchair to certain positions/zones where adaptive sub-games are launched as activities. The developed 2D sub-game was designed for a tablet PC attached to the wheelchair, although it can be used without the wheelchair. Patients have to make the correspondence between images and text (through the help of sounds) within a certain time limit.

4.4.2.3 Wattanasoontorn et al. (2013)

Wattanasoontorn et al. [308] present a classification of SG for Health based on four different aspects: game purpose, functionality, stage of the disease and players wellness (patient/non patient) and reviewed 108 games.

The authors adopted our taxonomy criteria [90] for classifying a health serious game application by functionality, and added some more characteristics such as:

- Game engine;
- Game platform;
- Connectivity.

Focusing on serious game subjects, they classify the serious games also by game purpose, in addition to game functionality. In the classification by game purpose they consider games:

- Focused on entertainment (FE): in addition to entertainment, it is necessary to move some parts of the body so wellness is obtained as a bonus.
- Focused on health (FH): the game is used to pass on skills or knowledge, but main goal is health.
- Focused on health acquisition and medical skills (FA): includes mostly simulation games with VR technology such as EMSAVE training simulation [316].

The authors consider also classifications based on two other related subjects: health and player. For health subject, they classify by state of disease. For player subject, they consider two types of players (player/non-player and professional/non professional), and both are included into the same classification. Figure 59 presents the classification suggested by the authors that builds upon our criteria [90].

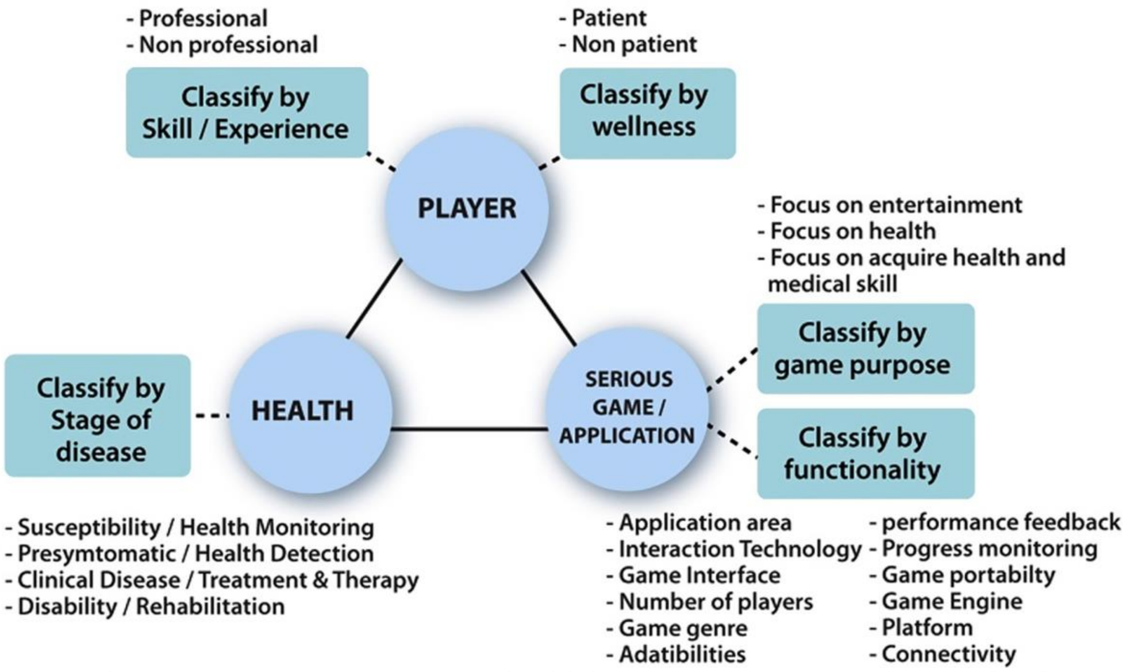


Figure 59 - Classification of serious games for health by Wattanasoontorn et al. (2013)[308].

4.4.2.4 Baranyi et al. (2013)

Baranyi et al. [288] based their implementation of a rehabilitation serious game for stroke patients, using the Nintendo Wii Fit Balance Board, on some of criteria we included in our taxonomy [90] such as: feedback, progress monitoring, adaptability and portability. The authors included also design criteria defined by Prensky (2007) such as: rules, goals, conflict, challenge and competition, and representation (related with basic game layout and the essential characteristics of each exercise). Additionally, they expanded these with aspects such as meaningful play (the player should see how his actions interact with the game) and challenge.

4.4.2.5 Davies et al. (2014)

Davies et al. [289] adopted our taxonomy for designing and classifying their serious game for balance rehabilitation and extended it with the inclusion of the following criteria:

- Simplicity: a high speed and complex game could generate frustration among the patients affecting the outcomes;
- Visually appealing;
- Movement and appearance of virtual objects; and
- Challenging.

For the development of the game they used user centered design methods, to ensure satisfaction with the game from both therapists and participants. In the game, the participant has to move his body to the extreme right and left sides, to catch with both hands, balloons of different colour that are dropped from the top of the screen.

4.4.2.6 Tavares et al. (2014)

Tavares et al. [309] aim to specify a features model for rehabilitation serious games that can be used to promote features reuse between games of this category. This model can thus serve as the basis for the development of others serious game focused on rehabilitation. In the proposed model of features they include our taxonomy criteria and extended them with criteria defined by other authors (Wattanasoontorn [315], Charsky [317] and Blumberg [318]) such as:

- Identity /Avatar creation (Blumberg [318]);
- Narrative (Blumberg [318]);
- Goals (Charsky [317]);
- Choices: refers to the number of options a gamer has prior to and during game play. Three different types are: expressive, strategic and tactical (Charsky [317]);
- Connectivity (Wattanasoontorn [315]);
- Platform (Wattanasoontorn [315]).

4.4.2.7 Cancela et al. (2014)

Cancela et al. [310] present a review on games for health focused in Parkinson Disease Rehabilitation, adopting our taxonomy for classifying the reviewed solutions and considering some extra criteria in order to extend our proposed taxonomy. The extra criteria included are the following:

- Game platform: the platform where the game is running, e.g. PC, mobile or a specific platform;
- Multiplayer: in the case that the game includes support for multiple players not necessarily playing at the same time;
- Patient follow-up: apart from scoring system and the games inputs, the platform can provide a parallel assessment of the patient taking into account the historical information.

4.4.2.8 Hao et al.(2015)

In order to classify serious games for elderly people and to find out what are the key principles needed in designing for elderly, Hao et al. (2015) [311] conducted a literature survey on serious games for the elderly, considering the different applications areas and the distinguished interactions features the elderly have. They identified 21 dimensions and extracted three categories from the identified dimensions: Cognitive, Gameplay, and Game structure. Table 7 presents the dimensions identified per category of the taxonomy suggested by Hao et al. [311].

Table 7 -Taxonomy of SG for elderly suggested by Hao et al.[311].

Cognitive	Gameplay	Game structure
Motor Attention Memory Language and Auditory Processing Visual and Spatial Processing	Adaptive Difficulty Social Interaction Engaging Immersive Motivation Biofeedback Problem solving	Flexibility Clinical Validity Customizable Portability Assessment Simulation and Interactivity

The dimensions grouped in the Cognitive category are:

- Motor: describes the main goals of the serious games. According to Hao et al. [311], assessment and recovery of the motion ability are the main goals since these are crucial for elderly people in giving them independence after stroke and other brain injuries.
- Attention: refers to the ability to concentrate on a particular situation, or object, or action or thought for at least a substantial amount of time.
- Memory: it is an ability that involves complex processes such as the storage and retrieval. With the age, working memory in elderly can be a problem, so for instance, a simple and intuitive interface can help in keeping memory processing to a minimum in gameplay.
- Language and Auditory Processing: refers to auditory acuity and comprehension of synthetic speech.
- Visual and Spatial Processing: refers to changes in vision.

The dimensions grouped in the Gameplay category are:

- Adaptive Difficulty: this mechanism is important for recovery or enhancement of the motion and cognition.
- Social Interaction: refers to social interaction when playing the game .
- Engaging: this feature is related to motivation, achievement, and task persistence.
- Immersive: refers to the state of consciousness when an individual is aware of his physical self who is surrounded and absorbed in an artificial environment, which created a perception of presence in a non-physical world.
- Motivation: refers to how people can be motivated in the game.

- Biofeedback: refers to the process of obtaining knowledge of physiological responses using hardware devices that measure and display physiological variables such as heart rate inconsistency and skin conductivity.
- Problem solving: it refers to a cognitive process of high-level which requires the variation and regulating of more routine skills.

The dimensions grouped in the Game Structure category are:

- Flexibility: refers to the flexibility and variability in movement of the users in gameplay.
- Clinical Validity: this dimension refers to the evaluation of the serious games, and whether the article provide any proof or evidence to support the uses of the games.
- Customizable: this dimension refers to whether the games have considered different players' tastes, motion and cognitive abilities.
- Portability: refers to the whether the games can be played at home.
- Assessment: refers to the ability to track user's progression through each stage and display it in an easy-to-read format.
- Simulation and Interactivity: refers to a type of genre that describes games which represent a simulated environment.

Upon the identification of the dimensions, the authors reviewed and compared several existing games, using the identified dimensions, presenting several guidelines for the design of games for elderly users.

4.4.2.9 Barret et al.(2016)

In studying game design principles that can be useful for upper-limb stroke rehabilitation, towards the creation of a model that enables a structured design of these kind of games, Barret et al. [312] included all the features present in our taxonomy proposal and also other features proposed by other authors.

In the paper the authors give an overview of various game design principles and the theoretical grounding associated to them. They also provide examples of how the game design principles exist in various custom and commercial game systems such as the University of Ulster games and the Wii Sports from Nintendo, among others.

4.4.2.10 De Lope et al.(2016)

De Lope et al. [313] propose a comprehensive taxonomy for serious games that is based on 16 criteria collecting features related with game design and development, platforms where the games run, and operational aspects such as use, users and distribution.

They divide Serious Games Taxonomies in General Serious Game Taxonomies and Specific Serious Game Taxonomies (meaning that it is specific to an application area of Serious Game). A taxonomy is general when it enables any serious game to be classified.

Their taxonomy is general and can help in choosing different options in several areas such as for example when developing a custom game, or when teaching a particular subject, or in a training skill. They applied the taxonomy proposal to 22 serious games and built a web application to support their proposal.

Table 8 presents the main dimensions composing their taxonomy. These dimensions are even further detailed and subdivided in their taxonomy.

Table 8 - Main dimensions in Comprehensive Serious Game Taxonomy of De Lope et al. [313].

Game development	Game platform	Game Design	Game Use	Game users	Business model
Authorship	Hardware architecture	Genre	Assessment	Target audience	License
Development methodology	Deployment	Narrative	Gameplay	Player interaction	
		Interactivity	Adaptation	Dedication	
		Context of use			
		Application area			

The taxonomy includes our proposed taxonomy criteria, along with other features from other existing taxonomies but provides other forms of classification of those features that are not found in other published classification systems making their proposal more complete than existing general proposals for classifying Serious Games.

4.5 Proposal for an extended Taxonomy of SGHR

Since the publication of our first taxonomy, several authors have been working on Serious Games for Health Rehabilitation and many studies have been published with games prototypes in this area. Based on literature review and partially demonstrated by the works described in previous section and in Chapter 2, our goal in this section is to present and describe our updated taxonomy taking into account the works, updates and innovations in game criteria that have been researched since our first publication in 2010.

The taxonomy constitutes a classification scheme that allows understanding the position and properties of the games in relation to one another. It will enable us to classify and compare in a more complete way the Serious Games in this area, in addition to contributing to form a knowledge base that can be part of the design and development process of a SG in Health Rehabilitation.

A classification scheme is necessary to manage the variability of serious games in Rehabilitation area enabling that games can be seen from multiple perspectives (application area, users, interaction, etc.). With a classification scheme, developers can select the most adequate techniques and desirable features and their tasks can be diminished.

Our classification scheme is multidimensional. Due to the complexity and variability of SG in Rehabilitation area, the upper layer of our taxonomy is divided in 12 dimensions: Application Area, Game interface/Environment, Game Portability, Game Genre, Narrative Genre, Feedback, Game Players, Monitoring/Assessment, Adaptation, Interaction, Game Platform, and Clinical Evaluation. All these dimensions contribute to characterize a SGHR.

To each dimension/criterion, we can associate a set of possible values or types. In some criterion, we can have more than one available type or value. We indicate this by using the term "mixed". For instance, the criterion "Interaction Goal" can have the value: competitive and collaborative. The "Mixed" value means that a game can have both values.

Next, we present a description of each criterion of our extended taxonomy proposal.

Application Area

This criterion was already proposed in our previous taxonomy, but it was updated in this version. The update includes adding a third type/category of rehabilitation: Behavioral rehabilitation, in addition to cognitive and physical rehabilitation, and the subdivision/detail of the Cognitive and the Physical dimensions.

Besides games addressing cognitive and physical impairments being much more common, we find some games reported for addressing eating disorders and phobias treatment. Based on this we also consider this category of Behavioral rehabilitation and divided it in rehabilitation of eating disorders and rehabilitation of phobias [319].

In relation to Cognitive and Physical dimensions:

- **Cognitive**: this dimension is divided, based on the classification adopted on RehaCom Game System [94].
- **Physical**: this dimension is divided in sub dimensions, based on the division adopted by Pirovano et al. [319].

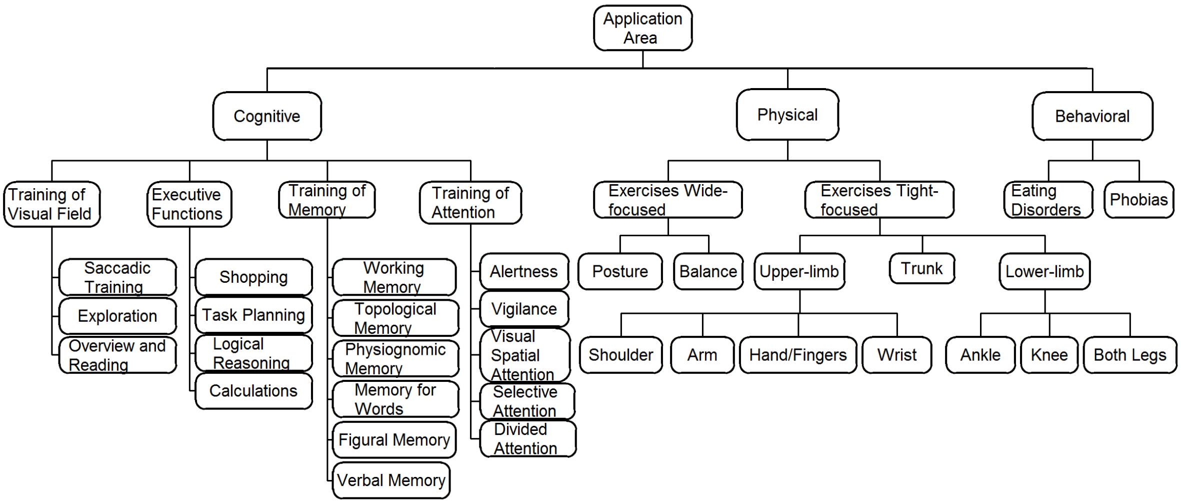


Figure 60 - Application Area.

Game Interface/Environment

This criterion was already considered in our previous taxonomy (in our game graphical interface criterion) and is described in section 4.2.1. Game interface/environment maps to the dimensionality of the game interface / environment used in the game. It can be two-dimensional (2D) or three-dimensional (3D).

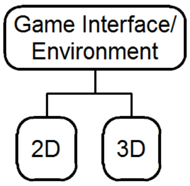


Figure 61 - Game Interface/Environment.

Game Portability

Game portability is concerned with the capability of the system to be used at home, or at a hospital or clinic. In our previous taxonomy, we considered the two types: clinic/hospital and home. In the present taxonomy, we add also the type: home-assisted, to represent the games that can be played at home but also require the assistance of a therapist.

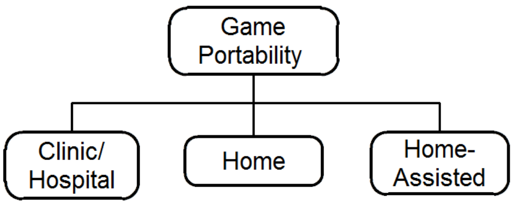


Figure 62 - Game Portability.

Game Genre

Following the criteria suggested by Wattanasoontorn et al. [308] and De Lope et al. [313], we add the following types to game genre: Action, Simulation, Strategic, Logic, Puzzle, Adventure, Sport, RPG, Exergame (after validation of our extended taxonomy among experts, we remove this criterion, as presented in section 4.7).

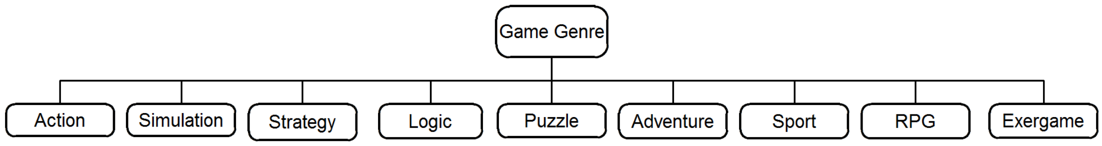


Figure 63 - Game Genre

Narrative Genre

Stories created in games can take different forms that are dependent of the game genre. For example, in a game like Tetris there is virtually no story while in a RPG game generally we can have complicated stories [320]. According to McDaniel et al. [320], stories used in SG are composed of characters (who is the protagonist?, what is the point of view of this protagonist? What forces is he facing? etc.), plots (what type of major overarching) and environments (Where is the story taking place? When does the story take place? Is the environment fantasy-based? How is player action constrained by the environment?, among others). The narrative is the actual content of the story, and is created based on story objects and narrative components, being a relationship between the components of causality, effect, space, and time [321].

In our taxonomy, we use the narrative genre criterion to refer to the thematic content or fantasy of the virtual environment of the task the patient has to do in a rehabilitation session. Similar to the "fantasy" criterion adopted by Pirovano et al. [319] in his classification of exergames, we follow his classification and divide the criterion in the same values. In functional rehabilitation, the thematic content is usually associated with ADL training [319].

Based on the classification of Pirovano et al. [319], we divide Narrative Genre in:

- **Activity of daily living** (ADL): many game tasks include ADL exercises such as: cooking, dressing, combing, walking, bicycling, or playing sports.
- **Realistic**: to represent non-ordinary activities of real life such as driving a plane.
- **Imaginary**: to represent an activity that is not feasible in real life, such as flying a spaceship, or riding a dragon.
- **Abstract**: we use this category to represent abstract games such as: memory and tic-tac-toe which do not include neither fantasy nor a realistic environment.

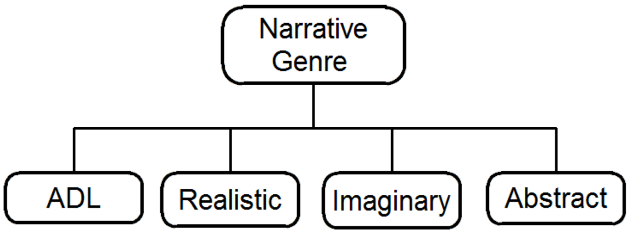


Figure 64 - Narrative Genre.

Feedback

This criterion refers to the response of the game system to the player actions and is used to guide the patients about the adequacy of their performance and how to improve it. Players should get an immediate response to their actions and they should be informed on their progress towards a goal [36]. In our previous taxonomy, we considered the criterion "Performance feedback". Now we detail the criterion and divide it in 2 types: type of feedback and representation mode.

For the type of feedback criterion, we adapt the classification of feedback of Taylor [36] dividing the type of feedback criterion in the following types:

- **System Interface Feedback**: refers to the simplest form: the system reacts to the actions of the player and responds accordingly. The changes in the system interface will give the player hints about the effect of their last actions and how he could continue. Some of these cues are specific to the game interface (e.g. highlights or other visual clues) and have to be learned within that context.
- **System-controlled Feedback**: this involves conveying hints on the patient's progress during the game, by, for example, presenting scores based on the performance of the player in the game. Requires that performance can be represented in a quantifiable way within the system. System interface feedback and system-controlled feedback are directly related to the gameplay and automatically created by the game engine and cannot be controlled by the therapist during the game session.
- **Therapist-controlled Feedback**: we adapt the term "instructor-controlled feedback" of Taylor [36] to the rehabilitation domain and consider this type of feedback as controlled by the therapist. This type of feedback is not automatically created by the game engine, it involves comments, advice and other therapy techniques that the therapist might apply with the patients as a complement to the system-controlled feedback and to the game therapy. It is focused on the therapy goals and not on the game goals (unless they are integrated).

System-controlled feedback can also be divided in formative feedback and summative feedback:

- **Formative Feedback**: is provided during gameplay and aims at giving the patients information about their progress and how they can change their actions, in order to achieve the task goals. According to Slomp et al. (in [36]) the appropriate frequency of feedback is dependent on the complexity of the game. For instance, they noticed that players of a complex game are likely to become frustrated if constantly provided with feedback, whereas a longer duration between feedback conveys the impression of success.

- **Summative Feedback**: is given to the patients through the game, in the final of the task, and aims to inform them whether or not they managed to reach the task goals (e.g. in terms final ratings) [322].

In relation to Representation Mode, feedback can be presented in visual form, auditory, haptic, or a combination of visual, auditory or haptic.

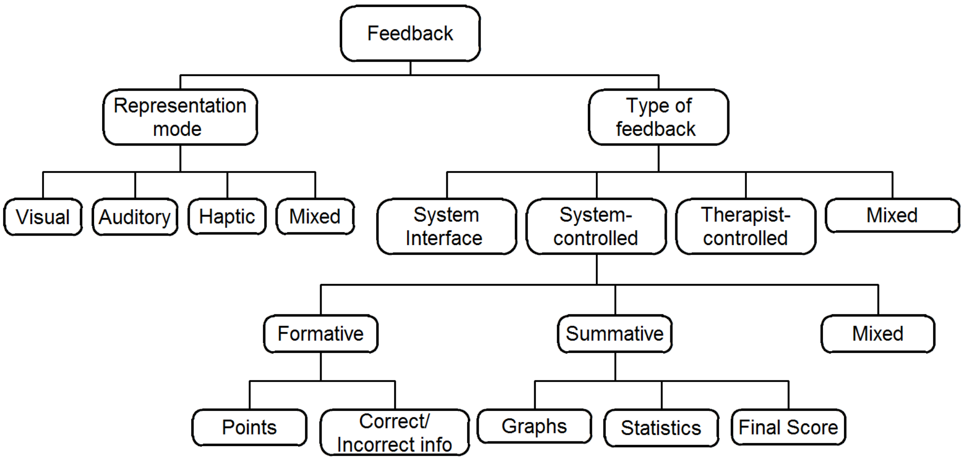


Figure 65 - Feedback.

Game Players

We substitute our criterion "Number of Players" from our previous taxonomy that was based on the interaction mode of the payers in gameplay by a more general criterion that includes the target group of the players and the interaction mode in gameplay.

- **Target Group**: refers to whom the game system is intended for. It can be: games for elderly rehabilitation, stroke or post-stroke rehabilitation, TBI rehabilitation and CP children. This choice is based on studies found in literature focused in these target groups.

- **Interaction Mode**: this will depend on the number of players in the game and can be further divided in single player or multiplayer mode if the number of patients playing the game is greater than one. Also, it can be a combination of the two modes, since a game system can have games to be played in single or multiplayer mode such as the game system proposed by Alankus et al. [89].

If Interaction Mode is multiplayer we can characterize it in relation to the interaction goal, presence of virtual agents (Agents presence), handicapping facility (Handicapping), and connection to a social network (Social Networking).

- **Interaction Goal**: the game can be collaborative if the patients play in cooperation to attain the tasks goal, or it can be competitive if they play against each other, or the game system can be competitive and collaborative, if it is composed by collaborative and competitive game tasks.
- **Agents Presence**: it can have the value *Yes* or *No*. If there are not enough patients to train the game tasks in multiplayer mode, the game can substitute a real patient with a surrogate virtual agent that will play against or in collaboration with a patient.
- **Handicapping**: it can have the value *Yes* or *No*. When patients are not on the same level of abilities, a mechanism of handicapping seeks to equalize opportunities to win for each user.
- **Social Networking**: Refers the possibility of the patient be connected to a social network of users that can play the game against him. It can have the value *Yes* or *No*. The players can play the game with their friends in social network from different locations.

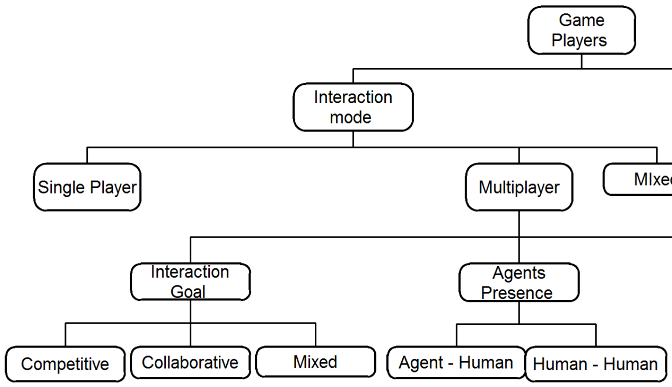


Figure 66 - Game Players.

Monitoring/Assessment

Feedback guides the patients about the adequacy of their performance and about how to improved it. In order to give feedback, the patient's performance in relation to the defined task goals has to be monitored/assessed. This monitoring can be done by the game (fully automated), the therapist (manual), or a combination of both (semi-automated). Monitoring can be done before gameplay (diagnostic), during gameplay (During Game-Monitoring) or after gameplay (Progress Monitoring). Our classification of monitoring is similar to the classification of monitoring of Pirovano [319], but we use distinct term names:

- **Pre-Monitoring / Diagnostic**: refers to the recording of data before the execution of the game (or gameplay). Before the start of the game, the therapist can make an assessment (diagnostic test) of the patient condition in relation of the parameters related with the game task and related data can be recorded; We call this pre-monitoring or diagnostic; it can have the value Yes or No.

- **During Game-Monitoring**: refers to the automatic recording of data during gameplay. It can have the value Yes or No. For instance, logs of the patients' movements or actions taken to be analysed after the game by the therapist. This monitoring can also be manual, mainly in Physical Rehabilitation, when the therapist supervises the gameplay, observing if the movements are done in the correct way, or if the patients is using compensatory actions. The record of data relative to the patient motion can be done by special input devices. Other authors use the term online-monitoring for monitoring during gameplay, such as Pirovano [319].

- **Progress Monitoring**: refers to recording of data after gameplay to analyse the patients' progress. It can have the value Yes or No. This data can be derived from direct observation of gameplay by the therapist and from review of statistics from previous game sessions, or from questions about patient/player experience about the different games.

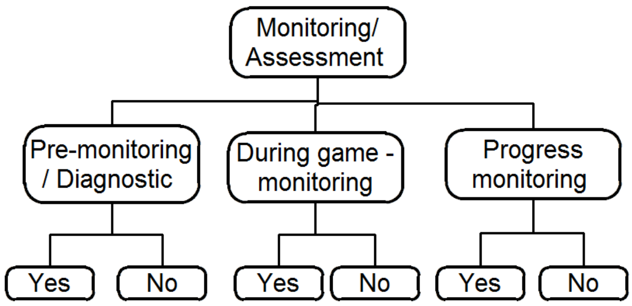


Figure 67 - Monitoring/Assessment.

Adaptation

In our previous taxonomy, we considered adaptation during gameplay. Now we consider a more general term to include also the adaptation that can be defined before the gameplay. Therefore, the game system can have an adaptation mechanism defined before gameplay (Configuration), during gameplay (Adaptability), in both of the previous moments, or no adaptation (none), as is illustrated in Figure 68. Other authors use the terms: Personalization, Customization, or simply Adaptation [319] [308].

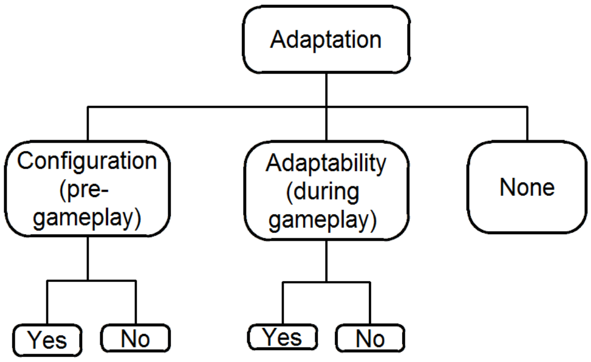


Figure 68 - Adaptation criterion.

In detail, this dimension is divided in:

- **Configuration** (Pre-gameplay): refers to the configuration of each exercise by the therapist according to the actual condition and skills of the patient. It can have the values Yes, or No. This configuration refers to the adaptation/ modification of parameters before the start of each game session to customize the game to the condition of the patient and thus follow his progress. In many games, this configuration includes the possibility of selecting a difficulty level.
- **Adaptability** (during gameplay): is the system capability to adapt dynamically game difficulty or challenge, according to the patient performance in the game. It can have the values Yes, or No; Game performance can be measured: e.g. based upon in-game scores like time, avoidable mistakes, among others [323].
- **None**: it does not have implemented any type of adaptation.

Interaction

This criterion substitutes the criterion "interaction technology" proposed in our first taxonomy. In our updated (extended) taxonomy, we decide to include a more general criterion "interaction" that includes interaction style, presence of multimodality, and interaction modalities present in the game, as illustrated in Figure 69 .

- **Interaction Style**: adapting the classification of interactivity of De Lope et al. [313] in their Comprehensive Taxonomy of Serious Games, we consider the Interaction style criterion divided in:
  - Standard: when the player uses the keyboard, a mouse, or a touch screen;
  - Active: when the player uses different peripherals or performs gestures (natural interaction) to interact with their own body.
  - Pervasive: when the game is integrated in the personal context of the player and the player interacts with real world objects.

- **Multimodality**: refers to the existence of an interface multimodal, that is, an interface that allows the possibility of having more than one input modality that can be selected, according to the patient abilities so that the patient can select the input interface that is more suited to his condition.
- **Interaction Modalities**: refers to the interaction modalities present in the game.

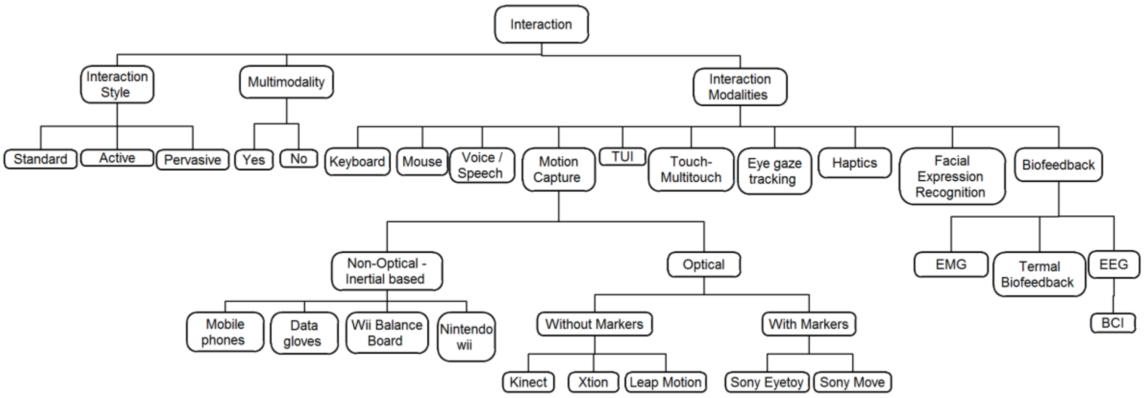


Figure 69 - Interaction criterion.

Game Platform

We follow here the game platform criterion of De Lope et al. [313] that divide a game platform in hardware architecture and game deployment.

- **Hardware architecture**: refers to the physical components of the game system and can be PC, Smartphone/Tablet and Console.
- **Game Deployment**: refers the environment on which the game runs: Web, Local or a combination of the two previous values (we indicate this with the term mixed). Wattanasoontorn at al. (2013) [308] refer the hardware architecture criterion using the term "Game Platform".

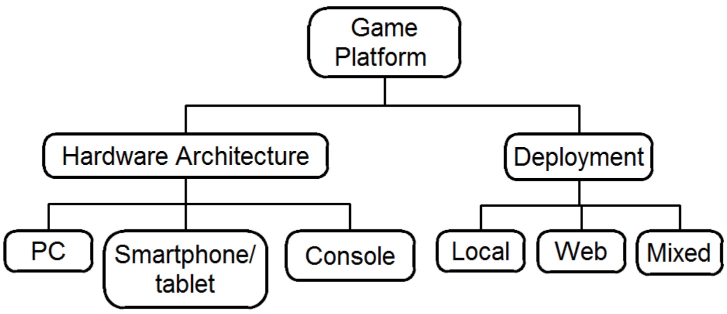


Figure 70 - Game Platform criterion.

Clinical Evaluation

This criterion was not considered in our previous taxonomy. It refers the user tests done with the game system. For each study, it is important the study aim, the study type (randomised control trial, pilot study, case control study, review, usability study, etc.), the instruments of measurement used and the number of participants.

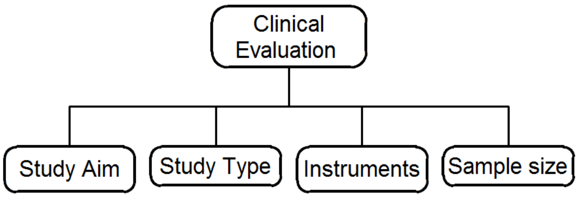


Figure 71 – Clinical Evaluation criterion.

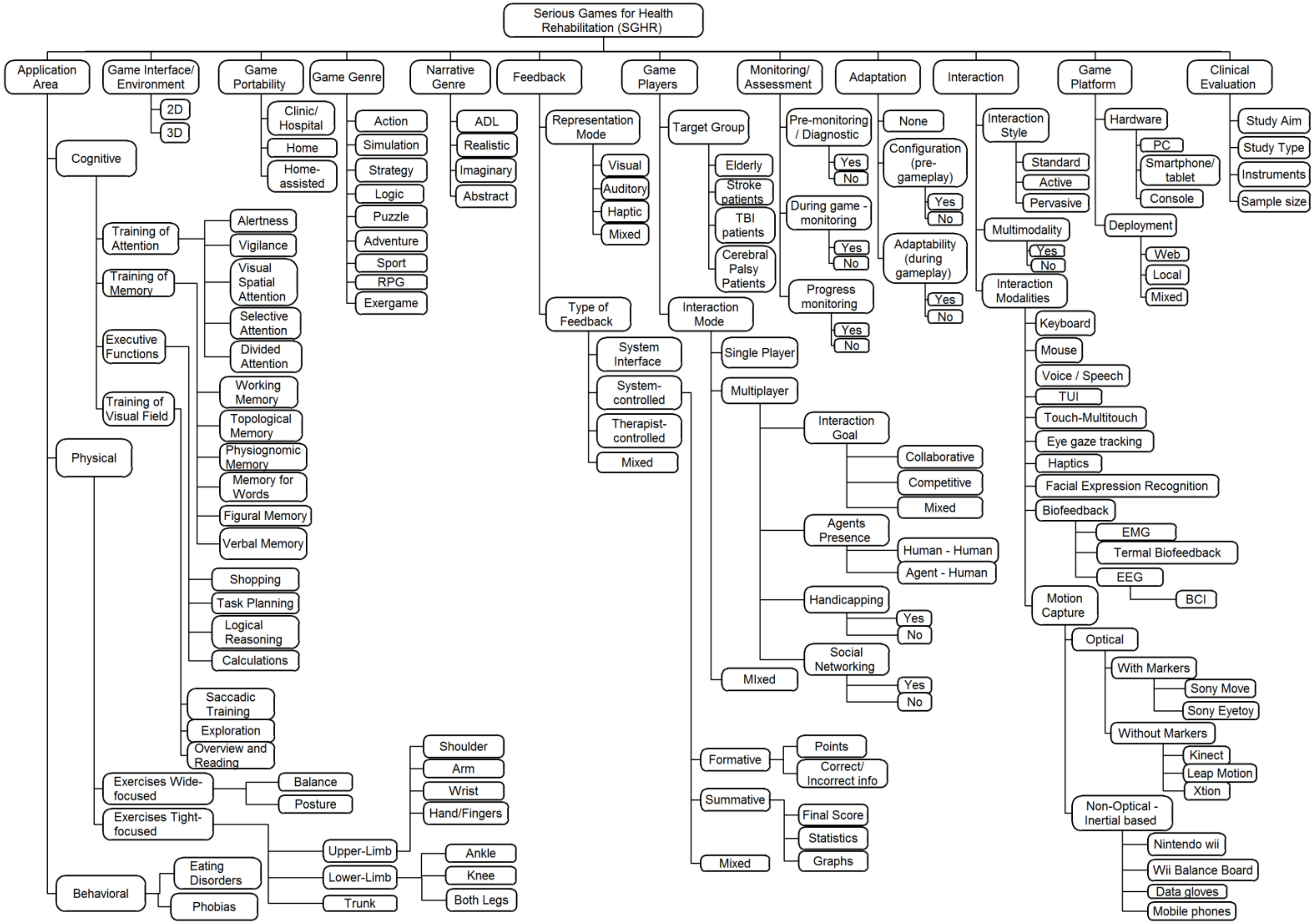


Figure 72 – Proposal for a SGHR Extended Taxonomy

4.6 Validation of the Extended Taxonomy

In order to validate the interest and applicability of the proposed taxonomy, for the classification and comparison of Serious Games in Health Rehabilitation (SGHR), we made a survey among experts in the area (serious game design, video game design, interaction design, health/ rehabilitation) and in related areas (informatics, computer graphics, computer programming). The participants of the survey were invited through electronic mail to fill a web-based questionnaire. The sample consisted in 198 experts chosen by filling one of the following criteria: authors that have referenced our original taxonomy proposal; authors and experts selected from the scientific committee of domain related conferences (such as the "Encontro Português de Computação Gráfica e Interação", "Vídeojogos" and "SGaMePlay - Serious Game and Meaningful Play Workshop"); and researchers and therapists participating in rehabilitation projects. In this section, we present a characterization of the sample, and the main results obtained.

4.6.1 Instruments

The survey questionnaire (in Annex A) consists of four parts that use a five-point Likert scale and some open questions. The first part records the respondents' demographic information, work area, area of specialization, frequency of computer use, frequency of smartphones/tablets use, frequency of playing games in PC, smartphones/tablets, consoles, and serious games, and prior experience in Video Games Design, Interaction, Computer Graphics, Computer Programming and in Health/ Rehabilitation area. The second part of the questionnaire is informative, describing the goal of the study, presenting the taxonomy proposal and a summary description of each of its dimensions.

The third part of the questionnaire was conceived to get information and to measure respondents' perceptions regarding our taxonomy proposal. This third part begins by questioning the relevance of each of the dimensions and sub dimensions of the taxonomy proposal and ends with three open questions. In the open questions, the respondents may: propose new dimensions to include in the taxonomy; propose changes or new subdivisions/subtypes for some dimension in the taxonomy, indicating a justification for those modifications, and may suggest/propose new names for any of the dimensions of the taxonomy proposal.

The fourth part of the questionnaire aims to obtain from respondents a global evaluation of the taxonomy proposal in what concerns its interest, usefulness, completeness, ease of use, and ease of extension. Then it questions about what is the intension of the respondents to use the taxonomy proposal for classifying their games and at what extent they would use it with that goal. The questionnaire ends by asking the respondents if they would like to receive the results from the study.

4.6.2 *Results*

A total of 198 invites to participation in the filling of the questionnaire were sent but only 32 usable responses were received. Data was analyzed using Microsoft Excel.

4.6.3 *Demographics Characterization of the Participants*

Table 9 presents the characterization of the participants that answered to the questionnaire in terms of gender and age. The majority are males (75%) while the remaining (25%) are females. In terms of age, most participants (50%) are between the ages of 41 and 50 years old, followed by 28.1% between 30 and 40 years old, while 15.6% were over the age of 50 and only 6.3% were less than 30 years old.

Table 9 - Demographics Characterization of the participants.

Characteristics	Frequency	Percentage
Gender		
Female	8	25.0
Male	24	75.0
Age (Years)		
Less than 30	2	6.3
30 - 40	9	28.1
41 - 50	16	50.0
over 50	5	15.6

Table 10 presents the characterization of the participants with respect to their work area and specialization.

With regard to the Job/Work Area, the majority (62.5%) of participants has a professional activity concerning to education (professors), 15.6% are researchers in Serious Games, 6.3% are software/computer engineers, 9.4% are researchers in Computer Science, 3.1% are researchers in Cognitive Rehabilitation and 3.1% are psychologists.

Concerning the Specialization Area, the majority (37.5%) of participants are specialized in Computer Graphics, 21.9% in technologies for Health/Rehabilitation, 18.8% in Serious

Games/Computer Games, 9.4% in Computer Engineering, 3.1% in Software Engineering, 3.1% in Digital Systems, 3.1 % in Personalized Systems/HCI and 3.1% in Psychology.

Table 10 - Characterization in terms of Work Area and Specialization Area.

Characteristics	Frequency	Percentage
Job/Work Area /Occupation		
Educator	20	62.5
Software/Computer Engineer	2	6.3
Psychology	1	3.1
Researcher /Serious Games	5	15.6
Researcher /Cognitive Rehabilitation	1	3.1
Researcher /Computer Science	3	9.4
Specialization Area		
Serious Games/Computer Games	6	18.8
Computer Graphics	12	37.5
Technologies for Health/Rehabilitation	7	21.9
Computer Engineering	3	9.4
Psychology	1	3.1
Software engineering	1	3.1
Digital Systems	1	3.1
Personalized Systems/HCI	1	3.1

4.6.4 Frequency of Use of Technology and Games

Table 11 presents a characterization of the participants based on the frequency with which they use computers, smartphones/tablets and play Games/Serious Games in different devices (PC, Smartphones/Tablets, Console).

Responses (Table 11) reveal that the frequency of computer use is very high for 81.3% of the participants and high for 18.8% of the participants.

Concerning Smartphones/Tablets frequency of use, the responses (Table 11) reveal that a majority of participants (53.1%) use these devices with a very high frequency, while 28.1%

responded high. The rest of the participants (18.8%) revealed a moderate use of these devices.

Table 11 – Participants' Frequency of Use of Technology and Games.

Characteristics	Frequency	Percent (%)
Frequency of computer use		
High	6	18.8
Very High	26	81.3
Frequency of Smartphones/Tablets use		
Moderate	6	18.8
High	9	28.1
Very High	17	53.1
Frequency with which you play PC games		
Very Low	6	18.8
Low	13	40.6
Moderate	8	25.0
High	3	9.4
Very High	2	6.3
Frequency with which you play Games on Smartphones/Tablets		
Very Low	4	12.5
Low	10	31.3
Moderate	12	37.5
High	4	12.5
Very High	2	6.3
Frequency with which you play Games in Console		
Very Low	14	43.8
Low	11	34.4
Moderate	3	9.4
High	3	9.4
Very High	1	3,1
Frequency with which You play Serious Games		
Very Low	9	28.1
Low	12	37.5
Moderate	6	18.8
High	5	15.6

Regarding the platforms and frequency of game play, for PC games, the responses (Table 11) reveal that the frequency is low for the majority (40.6%) of the participants, moderate for 25.0% of the participants, very low for 18.8%, high for 9.4%, and very high for a minimal (6.3%) number of the participants.

In terms of the frequency with which the participants play games on Smartphones/Tablets, the responses (Table 11) reveal that the frequency is moderate for the majority (37.5%) of the participants, low for 31.3% of the participants, high for 12.5%, very low for 12.5%, and very high for a minimal (6.3%) number of the participants.

In terms of the frequency with which the participants play games in Console, the responses (Table 11) reveal that the frequency is very low for the majority (43.8%) of the participants, low for 34.4% of the participants, high for 9.4%, moderate for 9.4%, and very high for a minimal (3.1%) number of the participants.

In terms of the frequency with which the participants play Serious Games, the responses (Table 11) reveal that the frequency is low for the majority (37.5%) of the participants, very low for 28.1% of the participants, moderate for 18.8%, and high for the remaining 15.6% of the participants.

4.6.5 Experience with Rehabilitation Serious Games and related areas

Table 12 presents the experience of the participants in several specialization areas related with Serious Games design and implementation for Rehabilitation: Video Games Design, Interaction, Computer Graphics, Computer Programming and Health/Rehabilitation area.

In terms of experience in Video Games Design, the responses (Table 12) reveal that the majority (34.4%) of participants has high experience, 18.8% have very high, moderate and low experience, while 9.4% have very low experience.

Concerning experience in Interaction, the responses (Table 12) reveal that the majority (40.6%) of participants has high experience, 25.0% has very high and moderate experience, while 9.4% has low experience.

For the topic Computer Graphics, the responses (Table 12) reveal that the majority (34.4%) of participants has very high experience, 21.9% have high experience, and 18.8% have low and moderate experience, while 6.3% have very low experience.

With reference to Computer Programming, the responses (Table 12) reveal that the majority (40.6%) of participants has very high experience, 28.1% have high experience, and 25.0% have moderate experience, while a minimal (6.3%) number has very low experience.

Lastly, for experience in Health / Rehabilitation area, the responses (Table 12) reveal that the majority (31.3%) of participants has high experience, 25.0% have very high experience, and 18.8% have moderate experience, while 12.5% have very low and low experience.

Table 12 – Participants' Experience in areas related with SGHR.

Characteristics	Frequency	Percent (%)
Experience in Video Games Design		
Very Low	3	9.4
Low	6	18.8
Moderate	6	18.8
High	11	34.4
Very High	6	18.8
Experience in Interaction		
Low	3	9.4
Moderate	8	25.0
High	13	40.6
Very High	8	25.0
Experience in Computer Graphics		
Very Low	2	6.3
Low	6	18.8
Moderate	6	18.8
High	7	21.9
Very High	11	34.4
Experience in Programming		
Very Low	2	6.3
Low	0	0
Moderate	8	25.0
High	9	28.1
Very High	13	40.6
Experience in the Health / Rehabilitation area		
Very Low	4	12.5
Low	4	12.5
Moderate	6	18.8
High	10	31.3
Very High	8	25.0

These results indicates that the respondents have high to very high skills and experience regarding domains of knowledge related to the main topic of research: Serious Games for Health Rehabilitation.

4.6.6 *Relevance of the Proposed Dimensions*

The participants were asked about the relevance of the dimensions proposed in our extended taxonomy proposal.

Our extended taxonomy proposal consists of 12 dimensions, which are: Application Area, Game Interface/Environment, Game Portability, Game Genre, Narrative Genre, Feedback, Game Players, Monitoring/Assessment, Adaptation, Interaction, Game Platform, and Clinical Evaluation.

Table 13 presents the results obtained regarding the relevance of each of the proposed dimensions.

In terms of the relevance of each of these dimensions in the taxonomy, the responses reveal that Feedback was the dimension most frequently chosen (81.3%) as very relevant by the participants, followed by Interaction (75.0%). Narrative genre was the dimension less frequently chosen (34.4%) in the category of "very relevant".

Regarding Application Area, the majority of participants consider this dimension very relevant, followed by 15.6% that consider it fairly relevant, 6.3% that consider it relevant and 3.1 that consider it slightly relevant and not relevant.

Table 13 - Results regarding the relevance of the proposed dimensions in extended taxonomy

Taxonomy Dimensions	Not Relevant		Slightly Relevant		Relevant		Fairly Relevant		Very Relevant		Total
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	
Application Area	1	3,1	1	3.1	2	6.3	5	15.6	23	71.9	32
Game Interface/Environment	0	0.0	1	3.1	6	18.8	6	18.8	19	59.4	32
Game Portability	0	0.0	2	6.3	5	15.6	9	28.1	16	50.0	32
Game Genre	2	6.3	2	6.3	9	28.1	5	15.6	14	43.8	32
Narrative Genre	2	6.3	2	6.3	10	31.3	7	21.9	11	34.4	32
Feedback	0	0.0	0	0.0	0	0.0	6	18.8	26	81.3	32
Game Players	0	0.0	0	0.0	4	12.5	6	18.8	22	68.8	32
Monitoring/Assessment	1	3.1	0	0.0	2	6.3	8	25.0	21	65.6	32
Adaptation	0	0.0	0	0.0	3	9.4	6	18.8	23	71.9	32
Interaction	0	0.0	0	0.0	2	6.3	6	18.8	24	75.0	32
Game Platform	0	0.0	1	3.1	6	18.8	7	21.9	18	56.3	32
Clinical Evaluation	1	3.1	0	0.0	2	6.3	6	18.8	23	71.9	32

Figure 73 presents the distribution of the responses regarding the relevance of the proposed dimensions.

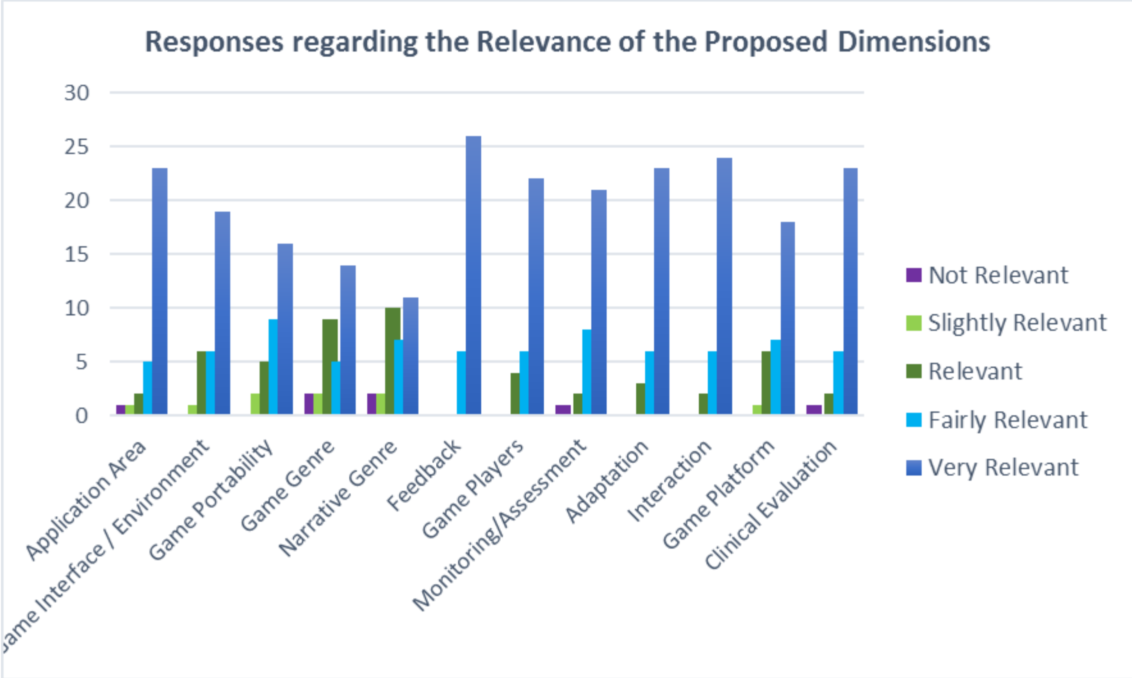


Figure 73 - Distribution of responses regarding the relevance of proposed dimensions.

4.6.7 Interest, Usefulness, Ease of Use, Completeness, Ease of Extension

The participants were asked about the Interest, Usefulness, Completeness, Ease of Use, and Ease of Extension of our extended taxonomy proposal.

Table 14 presents the results obtained regarding the Interest, Usefulness, Ease of Use, Completeness, Ease of Extension where we can observe that the mean value was, for most of the evaluated criteria, somewhere in the middle of the categories of "Somewhat Agree" to "Strongly Agree", being the lowest values in the criteria "easy to use" and "easy to extend". Although, having the lowest values, the evaluation was clearly positive for both of them.

Table 14 - Extended Taxonomy validation - results regarding Interest, Usefulness, Ease of Use, Completeness, Ease of Extension.

	Strongly Disagree		Somewhat Disagree		Neither Agree nor Disagree		Somewhat Agree		Strongly Agree		Total	Mean	SD
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%			
is interesting?	1	3.1	0	0.0	2	6.3	10	31.3	19	59.4	32	4.44	0.88
is useful?	0	0.0	2	6.3	4	12.5	9	28.1	17	53.1	32	4.28	0.92
is complete?	1	3.1	0	0.0	6	18.8	14	43.8	11	34.4	32	4.06	0.91
is easy to use?	1	3.1	7	21.9	5	15.6	13	40.6	6	18.8	32	3.50	1.14
Is easy to extend?	1	3.1	2	6.3	8	25.0	11	34.4	10	31.3	32	3.84	1.05

The positive evaluation of the proposed extended taxonomy can be observed in Figure 74 that presents the distribution of the responses regarding the five criteria: Interest, Usefulness, Completeness, Ease of Use, and Ease of Extension.

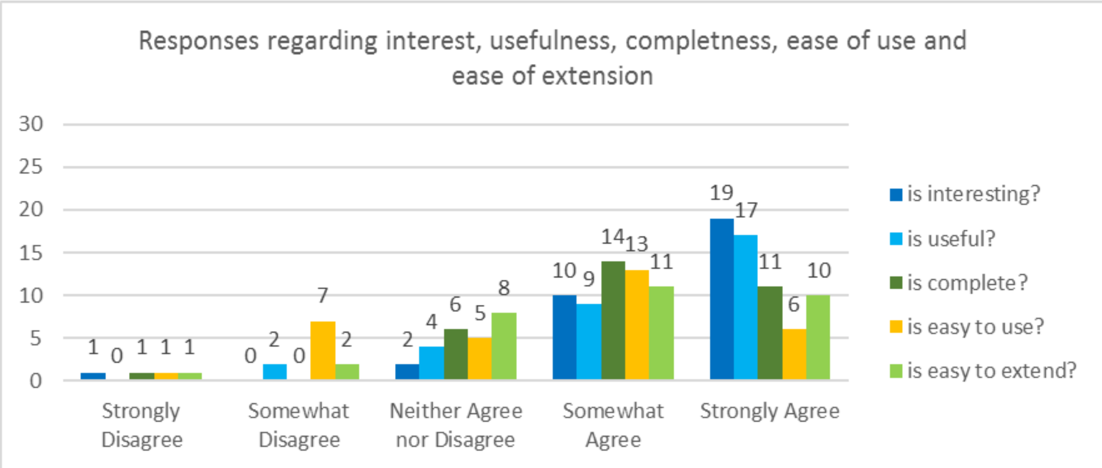


Figure 74 - Taxonomy Validation – answers regarding Interest, Usefulness, Completeness, Ease of Use, and Ease of Extension.

4.6.8 Intention to use

In the questionnaire, the participants were asked about the intention to use our extended taxonomy proposal in classifying their games.

Concerning this dimension of the validation, the obtained results were clearly positive.

Figure 75 presents the distribution of the responses regarding the intention to use our extended taxonomy proposal in classifying their games. Notice that the fourth statement was formulated in the negative form, and thus the “disagreement” mode actually corresponds to the support of our proposed taxonomy.

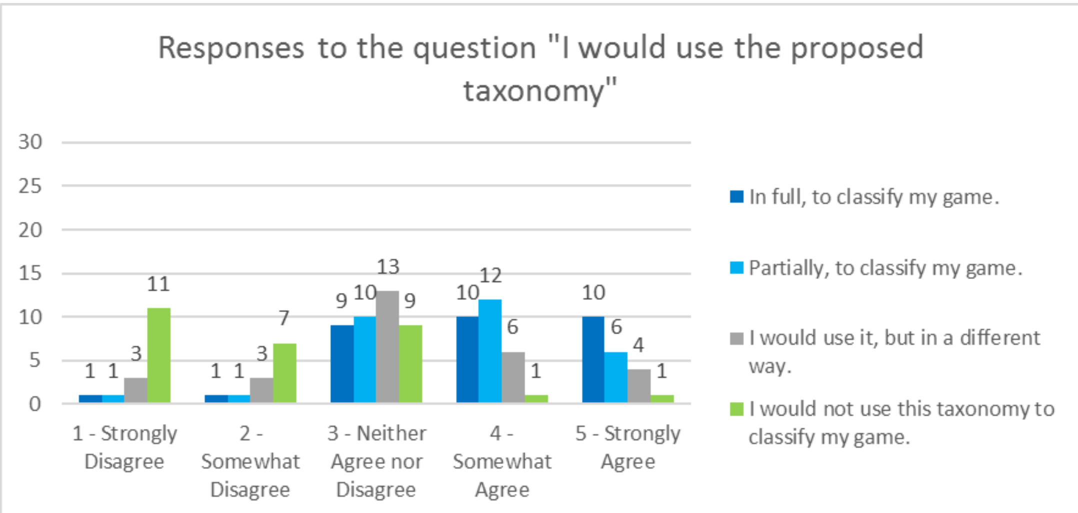


Figure 75 - Taxonomy validation **-** Responses to question “I would use the proposed taxonomy”

4.6.9 Open Questions

The open questions we included in the questionnaire were:

- 3.13 What other dimensions would you like to see included in the taxonomy?
- 3.14 Do you think that the subdivisions /subtypes proposed for any of the dimensions should be changed? In that case, what new subdivisions / subtypes do you find useful to define for that dimensions? Indicate them here and justify.
- 3.15 Regarding the names considered for the dimensions, would you change the names of the dimensions? If so, suggest / propose the new names here.

In what concerns new dimensions proposed, some of the dimensions suggested by participants included: Interoperability, Data standards; kind of license (free; proprietary); The license fee (free; commercial; ...); date of first release; last version and date; publication where described.

Regarding modifications to the subdivisions, some of the new subdivisions suggested and comments given by the participants were:

- Interaction dimension should not come associated to the specific sensor;
- Relevance of the game interface is strictly coupled with the application;
- Game Platform/Hardware - might not be relevant;
- Clinical evaluation should not be included for the classification since there are a lot of possibilities to do so;
- the Exergame genre is more like to be a "purpose genre" and should not be mixed with the other genres that are more "content genres";
- game genre can be skipped;
- Cognitive-Training of Memory should include Visual Memory instead of Figure Memory;
- Cognitive-Training of Memory should include Auditory Memory;
- Training of Visual Field trains also Attention and Reasoning;
- Training of Planning and Training of Reasoning should be new subtypes of Cognitive;
- Behavioural is very limited, there are a lot of subtypes that also could be considered;
- Physical should include Auditory Training and Vision Therapy or Vision Training or perhaps a subdivision called Sensorial should include at least these two kind of training on sensorial impairments;
- Game Portability could include ""Everywhere"" because you can train your memory in a bus stop for example to complete your rehabilitation;

- Virtual Reality and Augmented Reality should be added to the taxonomy in some place;
- Game Genre: change puzzle by educative;
- Feedback: include information about the interaction and state of the other players;
- Target group: sensorial impairments and physical injuries should be considered;
- Interaction modalities should include voice and special devices;
- Clinical Evaluation should include: procedure, participants (not only sample size but also age, diagnostic, etc.), results;
- It would be better not include concrete names of products (Wii etc.) in a taxonomy - Game platform and game portability intersects;
- Some of the subcategories are not exhaustive such as behavioral.

In what concerns the new names suggested and comments given by the participants this included:

- Quiz must be reformulated because it is not clear at all. Presenting the taxonomy beforehand is biased and leads to wrong results;
- Some of them could be a bit more explicit, namely those that use acronyms.

4.7 Improved Taxonomy Proposal (after Experts Validation)

From the analysis of the responses obtained from the survey, we decide to improve our taxonomy by considering some modifications to some of included dimensions and we present here an improved version for the Taxonomy proposal, after analysis of the responses given by the inquired experts.

The modifications we include focus mainly the following dimensions in our extended taxonomy proposal:

- Application Area
- Game Genre
- Interaction
- Clinical Evaluation.

In Figure 76 we present our improved extended taxonomy proposal for the classification and comparison of Serious Games in Health Rehabilitation.

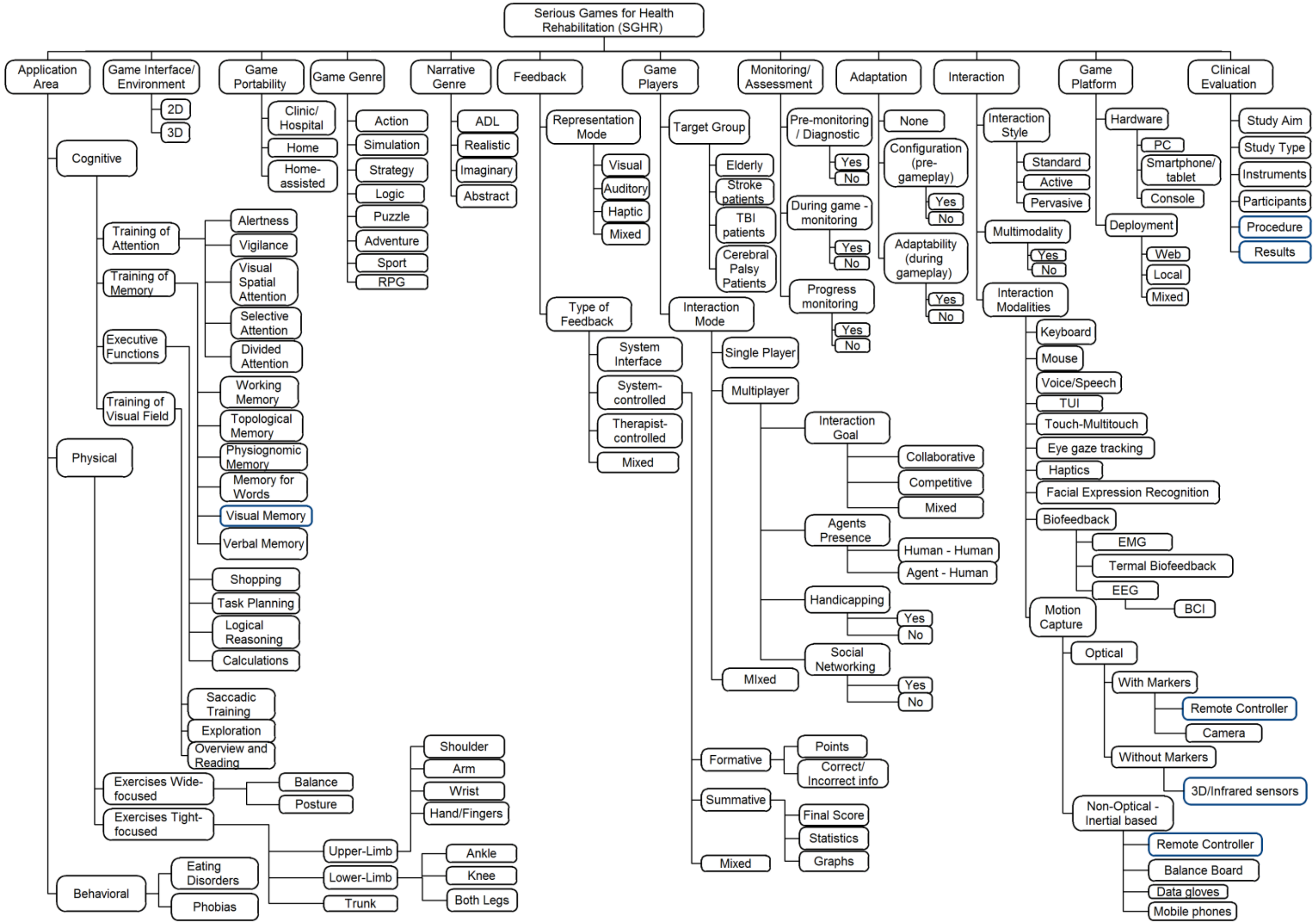


Figure 76 - Our improved taxonomy proposal for SGHR, after validation.

4.8 Summary

This chapter described our first taxonomy proposal for SGHR and provided an application of the taxonomy in the revision of several serious games for motor and cognitive rehabilitation that were described in chapter 2. This comparison allowed acquiring an overview of the SGHR field based on the proposed taxonomy, contributing to identify potential and field problems.

The revision made also included main modalities present in reviewed games and therefore a classification focused on use of NUI was also provided.

In order to update our first taxonomy proposal we presented an extended taxonomy based on literature review. A questionnaire was designed in order to make possible a validation of the proposed taxonomy among experts in the area and in related areas. We described the used procedure and discussed the results obtained from this validation. Generally, experts validated and evaluated very positively our proposal at the several dimensions of analysis. Experts made some suggestions, which lead to refinements and to a final proposal that embraces the aforementioned suggestions.

Chapter 5

SGHR Framework Architecture

In this chapter, we begin by presenting the main considerations, design requirements, reference system and guidelines taken into account in the design of the framework we propose for the development of Serious Games in Health Rehabilitation. Then we present the proposed framework with a description of its main modules and lastly we relate it to other frameworks found in the literature, discussing how they differ from our approach.

5.1 Framework Considerations/Requirements

As discussed in section 2, it is now believed that with computer-assisted rehabilitation and with Serious Games the efficacy of the rehabilitation process can be improved, by increasing the motivation of patients in rehabilitation sessions. Following this research line, our main goal is to propose a framework for the development of Serious Games that integrates a set of features: natural and multimodal interaction, social skills (collaboration and competition) and progress monitoring which can be used to improve the rehabilitation process.

In order to validate this proposal, we designed and implemented a Serious Game system that can be used by any type of user including elderly people and patients suffering from a disability or impairment to train/exercise the rehabilitation tasks prescribed by the therapists. The game based therapy is expected to improve the efficacy of the rehabilitation process. This improvement in the efficacy follows from an increase in the patient's motivation when exercising the rehabilitation tasks.

Some of the key issues associated with our research and foreseen in the proposed architecture are described in the following subsections.

5.1.1 Design of the Rehabilitation Tasks

The design of the rehabilitation tasks is a very complex issue that depends on the kind of disabilities of the patient in rehabilitation. These disabilities can be diverse and so it would be necessary a program adapted to the patient needs in order to achieve the best results in the rehabilitation program. Therapy efficacy is the most important feature in order to use a Serious Games system in cognitive or physical rehabilitation.

In order for the therapy to be effective, it is very important that Serious Games can be developed in collaboration with experienced therapists that can contribute in defining validated rehabilitation tasks that can be then translated into game tasks. The design of the rehabilitation tasks would thus require a multidisciplinary team from the medical field composed with doctors, nurses, psychologists, physiotherapists, and therapists. Importantly, it would require professionals of the game design field. This may be difficult since it implies communication between different professionals (and languages).

As it would be difficult in our case to arrange a multidisciplinary team responsible for designing the games, our intention is to use a reference system in which we can base the design of our games and validate our system. Our goal in this work is to minimize the complexity associated with the design and use an existing and established system as a reference for the games design to develop identical game tasks, except for the new features we intend to test.

5.1.2 A Reference System: RehaCom

From the literature review conducted, we found that the most established system that is used in many rehabilitation clinics and that has results proven scientifically is the RehaCom System [94, 98]. This system is composed of a set of serious games that are used in cognitive rehabilitation sessions. Our intention is to design our games using the concept of the games of RehaCom but to improve some features of these games to study the motivation and satisfaction of patients in playing our games (built upon RehaCom's concept of the game).

RehaCom is a system widely used and tested in the area of cognitive rehabilitation. Its effectiveness has been demonstrated in a number of studies all very well referenced (with a description of the study conducted) in the RehaCom Catalogue [93, 98]. Since this system is well established in various hospitals and clinics, with a great number of patients, we can more easily have access to its studies of patients in rehabilitation programs. Consequently, we can more easily study its efficiency. For these reasons, we find it to be a reference system in this area and choose it as our main case study to start building our games.

Although other cognitive rehabilitation systems are used in many clinics/hospitals such as the systems described in chapter 2 (Parrot, StrongArm, INTRAS), the RehaCom system has results proven scientifically in a stronger way, with a large number of patients and a large number of studies.

Using our proposed taxonomy described in Chapter 4 (section 4.2.1), we may classify RehaCom as follows:

- **Application Area -** The system assists in cognitive rehabilitation. In this field, applications can be various: clinical psychology, geriatrics, developmental psychology, sport psychology, work psychology and driving.

- **Interaction Technology -** Training with the system can be carried out using a special panel, the computer keyboard, the mouse or a touch screen. As in the major part of cases the normal keyboard is not appropriate to the rehabilitation training, due to its complex use and demands at the fine level motility. The special panel of RehaCom reduces the operation commands to a necessary minimum number, being composed with 5 large keys and 2 special keys, as shown in Figure 77. The large surface of the panel and the robust form of the 5 reaction keys allows that patients with motor deficiencies or disabilities can handle the panel with safety.

Figure 77 - The Special Keyboard that integrates the RehaCom System .

- **Game Graphical Interface -** The graphical interfaces of the games that compose the computer system are all two-dimensional, as it can be seen in the RehaCom game examples presented in section 2.3.2.4.

- **Number of Players** (Single/Multi-player) - RehaCom games are to be played with only one participant at a time.

- **Competitive/Collaborative -** The system does not have any Competitive/Collaborative features. In fact, it only allows one participant at a time; consequently, it does not permit a competitive or collaborative interaction with other patients.

- **Game Genre** - The system supports games of varying genres. Games classification can be made by category area in which they are included in RehaCom Software system. These categories are shown in Table 2.

- **Adaptability** - The training programs are adaptive which means that task difficulties increase automatically during training progress so that tasks cannot be too easy or too difficult to the patient, but adjusted to the performance possibilities of the patient. This induces a high level of motivation in the training task. In the Parameter menu there are additional options to an individualized training. There is also a possibility to integrate some specific elements in the patients training, like for instances the use of photos from family and friends of the patients in the program "Memory of Faces". The training task can be interrupted or terminated at any time, by the therapist or by the patient himself.

- **Progress monitoring -** For the continuous evolution of the training, the relevant results of the program are analyzed. These training results form the basis to change the difficulty level. The results of all training sessions are recorded and a new session begins where the last one ended. It enables to monitor progress and adjust the training goals as necessary. When the training time defined is up, the session ends. During the training, the therapist can analyze the patient's progress and identify and influence his performance weaknesses. The results of the training sessions can be used to control and eventually adapt the therapy goals.

- **Performance feedback -** The patient gets information of his progress from the system in several ways during the training session. If the patient makes a mistake, he receives specific feedback in the form of simple graphical elements in the screen or by acoustical feedback. In the beginning of the training, the patient reads the instructions. In many programs the instructions are based on the "learning by doing" principle. In the end of a session, the patient can see his progress, from session to session, by means of a performance chart that appears on the screen. In addition, a more detailed description of the results is also available. Also, in the transition to a higher difficulty level, the patient gets informed, in verbal way, about which difficulty level he will continue to train. It is also provided an orientation about the necessity for additional training and information about the aspects the patient has to give more attention.

- **Portability -** Training requires the presence of the therapist at the beginning and at end of training in order to discuss the patient's training goal and results, but the programs are designed to enable the patient to train on his own most of the time. Therefore, it can reduce considerably the workload of participants in the therapy.

5.1.3 Interaction with the System

People in rehabilitation can have cognitive and motor disabilities which difficult the way they interact with the system preventing them from using traditional techniques, such as mouse or keyboard. This interaction with the system should then be more intuitive and easy to use, according to patient's disabilities. For these reasons, alternative means of interaction should be considered.

The use of more natural interfaces can benefit the process of rehabilitation. **Natural interfaces** enable an easier, intuitive, and realistic interaction as they often eliminate or diminish the use of artificial devices specific for interaction while enabling users to interact directly with real-world objects (for example, using a racquet in a tennis game) without using an intermediary device.

The use of only a single device can also limit **accessibility**, which is why the combination of multiple input and output modalities is an important objective. With a multimodal or adaptive interface, the patient can choose the input from what would best suit his or her disability conditions. Additionally, this will ensure a more immersive and realistic user experience.

5.1.4 Feedback

A clear and immediate feedback is very important in rehabilitation. The patients need to know and understand what they are doing right or wrong when making their actions when playing a game. In traditional rehabilitation, patients receive verbal feedback from the therapist to correct their actions, or movements and posture. Games should also provide this feedback to the patients.

Interface design guidelines that can be applied to game design can help in creating also a useful feedback and should be tested in particular for patients that need special attention such as elderly patients [324].

5.1.5 Social Interaction

Games and game concepts have a stimulating effect on engagement in tasks. In addition, social interaction in games has demonstrated positive effects in healthy subjects in terms of player experience [85]. Social play can be achieved by the incorporation of competitive and collaborative tasks in the rehabilitation games [62]. Social factors included in many games have had effects on people's enjoyment when playing the games. This may increase the social connectedness and motivation in rehabilitation patients to keep practicing the exercises they need.

This social interaction can be achieved in games through the following forms:

- **Collaborative tasks**: Collaborative games can provide a friendly game play and improve social bond between players. The goal in the game is not to win as a player, but as a team of players.
- **Competitive tasks**: In competitive games, beating the opponent can be very motivating; however, the patients would need to be in the same level of abilities and thus, using the concept of handicap may be useful.
- **Mixed Collaborative and Competitive tasks**: the games can have collaborative and competitive tasks.

5.1.6 Progress Monitoring

Another key feature to include for Serious Games in health rehabilitation is the ability to detect, log, and analyze patient's task performance (cognitive or motor), as prescribed by the therapists, in order to evaluate the patient's progress in the therapy.

This feature is related with other important features such as configuration and tasks scheduling, data tracking, assessment of the patient performance, adaptability and monitoring.

Configuration refers to the possibility of the therapist (in some cases, also the patient) modify some of the parameters of the game to customize the game to a specific patient, depending on his actual condition and his progression. For instance, it may consist of configuring a difficulty level (such as mentioned in [6]). In traditional rehabilitation, the therapist defines the exercises the patient has to train in each session. Using a rehabilitation Serious Game system the therapist should define the games that should be played by the patient in each session and the system should then provide to the patient the correct tasks (games) at each session. In other words, the system should schedule the tasks that were defined for a patient at a correct time.

In motor rehabilitation, in order to check if the patients are performing exercises correctly or not, it is necessary to capture data relative to their motion. It is important then to choose an adequate input device at design time that will capture all the motion requirements of the game tasks. In cognitive rehabilitation, it would be necessary to detect and log the actions of the patient in the game. Depending of the application, in cognitive and motor rehabilitation, additional data could be recorded as well such: as physiological data tracked by specific sensors, event logs, and summary results useful for assessment. In traditional rehabilitation the only data that is collected results mostly from the observations of the therapist, thus the possibility of having available data collected using data tracking from the patient represents a great benefit.

In addition to feedback directed to the patient, it is important that the therapist receives also feedback from the game sessions in order to assess the performance of the patient and direct the progression of the therapy. This captured data based on the progression of the therapy can take the form of graphs that can be consulted for further analysis.

Adaptability is the adaptation during the execution of the game (or gameplay), that is the dynamic equivalent of configuration. This adaptability refers to the fact that the game can be adjusted according to the actions or movements of the patient during the execution of the game. This actions or movements are dependent of his actual condition and the game can thus match his condition. In a traditional rehabilitation session, the therapist usually modifies the exercises according to the actual condition of the patient, for example by making an exercise easier if the patient is tired. Like configuration, adaptation can be used to customize the game tasks to the patient condition and thus can contribute to increase the efficacy of the therapy for different patients. This can also contribute to increase the motivation of the patient as he plays the game according to his capabilities. This automatic adaption is referred also in game design studies as Dynamic Difficulty Adaptation. This adaptation is referred also by Burke [6] as a way of maintaining an appropriate level of challenge in the game by changing game elements that make the game easier, or harder, according to the user's performance.

Monitoring during game execution refers to the supervision of the patient actions and movements during the execution of the game session. In traditional rehabilitation session, the therapist supervises the movements and actions of the patient to check if its execution is done in the correct way, and advises the patient if they are not correct. When executing movements in physical rehabilitation, and mainly due to pain in impaired limbs or in post-stroke rehabilitation, due to unilateral nature of some physical impairments, the patient may use compensatory motions to achieve the exercises goals and therefore it is very important that the therapist supervises the patients in a continuous way. Using a Rehabilitation Serious Game system, this supervision during the execution of the game sessions can be done in an automatic way by using the data captured from the patient motions or actions in the game. When playing the game, the patient is focused in the game activity and his attention to the correctness of the movement may be decreased, resulting in an increased number of incorrect movements or compensatory actions. Another aspect to mention is that adequate feedback should be given in conjunction with monitoring when the patient chooses an incorrect option or makes an incorrect movement. This feedback can take the form of visual clues or verbal warnings. In these cases, a possibility of repeating the movement or the task is given. For instance, in RehaCom's training of memory game, every time the patient chooses an incorrect word he has to repeat the task a predefined number of times, in order to consolidate it.

5.1.7 Home Rehabilitation

From literature review, we can see that work developments are being made towards the creation of applications that use low-cost devices, which would be conveniently accessible and easily affordable for people in general -- an essential aspect in the Rehabilitation domain.

The use of low-cost systems can foster a home rehabilitation and create more opportunities for the patients to perform the necessary exercises in their recuperation plan. Hence, an important aspect to consider in our framework is the use of an inexpensive interaction technology that can be feasible for home use, thereby promoting more frequent gaming for the patients. The home rehabilitation tool should not be used to replace the therapist, but instead serve as a supplement to the assisted rehabilitation, allowing a recuperation plan to be completed partly at home.

The patient can then exercise the therapy plan without needing the continued assistance from a health professional, who may not be always available. Additionally, it can save the patient from frequent visits to the rehabilitation center, which in some cases might be problematic or uncomfortable depending on factors such as the location of the rehabilitation center and on the disability condition of the patient.

5.1.8 Agents and Virtual Players

In multiplayer games we could consider the possibility of using agents, with different responsibilities such as: agents as therapists, agents as virtual co-players, agents responsible for progress monitoring, agents for choosing the patients at the same level of handicap or for choosing the level of handicap of each player. The use of agents with the responsibilities mentioned, with emphasis on agents that may be co-players of the serious games developed may be very useful since patients would always have teammates for collaborative play and competitors for competitive play.

5.1.9 Accessibility and Usability

When dealing with technology, accessibility and usability are features that are necessary to address. In what concerns the design of effective rehabilitation games, they become even more relevant since the target group is composed by users with impairments that may prevent them from using some input devices or from using interfaces they may consider confused and unclear. If the target group is formed by elders, they may have additional cognitive and physical impairments related to old age that may request for interfaces more adequate to their condition.

In rehabilitation, accessibility can be improved through several factors [319] such as improving the usability of the games, and by providing facilities of configuration and adaptability, since with these facilities the game can be configured to the patient actual condition. Usability of the game can be increased with a clear and immediate feedback on the patient actions in the game and in the interfaces for navigating in the selection menus, with clear graphical user interfaces and with the use of NUIs. Another extra benefit is that a higher usability can conduct to a higher technology acceptance, enabling that patients feel safe and trust in the system, which conducts possibly into a higher motivation to complete the therapy.

5.1.10 Validation

In order to use Serious Games as a valid therapeutic alternative to traditional Rehabilitation, the Serious Game system should be validated with long-term studies that evaluate therapy in a more complete way. Some clinical studies have been published. For example, Cameirão et al. [75] developed the Rehabilitation Gaming System (RGS), a VR-based neurorehabilitation system for the upper limb and fingers, and validation was carried out with eight patients during twelve weeks. At the end of the treatment, the RGS group, when compared to a control group, displayed significantly improved performance in arm speed and faster improvement over time. Golomb et al. [325] performed a clinical pilot study during one year with three adolescent CP patients, using their glove-enabled upper-limb exergame at home. The use of the system at home enabled an autonomous use, but the authors found many issues regarding medical, technological, safety, personal, and social problems. Pirovano [319] refers a pilot test of three-months of his autonomous exergames with post-stroke patients at home, in order to assess usability, adherence, acceptance, and effectiveness of the final system, but has, at the time of the paper, only preliminary results showing good adherence, satisfaction, and acceptance of the technology.

Cruz et al. [100] describe a study to determine the treatment intensity and patient adherence to home-based cognitive training strategies (through Web-based cognitive training) where the patients used the COGWEB cognitive training system in a daily base during 18 months fulfilling at least four weeks of training supervised remotely and observed that they performed more cognitive training.

Evaluation of the experiments can be made by questionnaires, direct observation or by assessment of the rehabilitation progress of the patients, done by a therapist.

Some of the evaluation measurements that can be considered in experiments are:

- Usability: easy to learn the interaction? Clear to use?
- Attractiveness: like the game? Felt involved?

- Dropouts rate: how many times did the patient quit the game?
- Time in play: Average time in game play?
- Game play frequency: how many times did the patient play?
- Average time of recovery: how long take to recover?

5.2 Proposed Architecture

5.2.1 Introduction

In this section, we start by presenting and describing an architecture proposal for the development of Serious Games for Health Rehabilitation.

In order to demonstrate that Serious Games can be used to increase motivation of users including patients in rehabilitation, we propose a framework for the development of Serious Games for Rehabilitation that integrates a set of features that we identified as relevant to improve the rehabilitation process, such as: natural and multimodal interaction, social skills (collaboration and competition) and progress monitoring.

The support for several different devices is very important in rehabilitation since games for rehabilitation can present very different requirements in terms of tracking (in physical rehabilitation), in comparison with entertainment games, and in terms of accessibility. In such a way, special hardware that can support these requirements can be necessary or desirable. In addition, the integration of different devices is important since the users of these games – the patients, can be in several different conditions, presenting very different impairments (for instances in stroke rehabilitation) that can limit their access to some devices. The development of games for different conditions and pathologies and in an efficient way is very important in this area.

5.2.2 Framework Architecture

Figure 78 presents our proposed architecture for the development of Rehabilitation Serious Games that supports several different devices.

When a patient chooses a game to play, the game engine runs the chosen game and collects inputs, renders the virtual environment, runs the game logic, and provides the feedback that is related to the game. Patient inputs can be provided by different tracking devices and are mediated by the Input Modality Manager Module that makes an abstraction to support many different devices. The Logging & monitoring module saves the tracked data into local files. The game is shown to the patient through an output system, such as a display and can also use the input devices (as is in the case with haptic/force feedback devices).

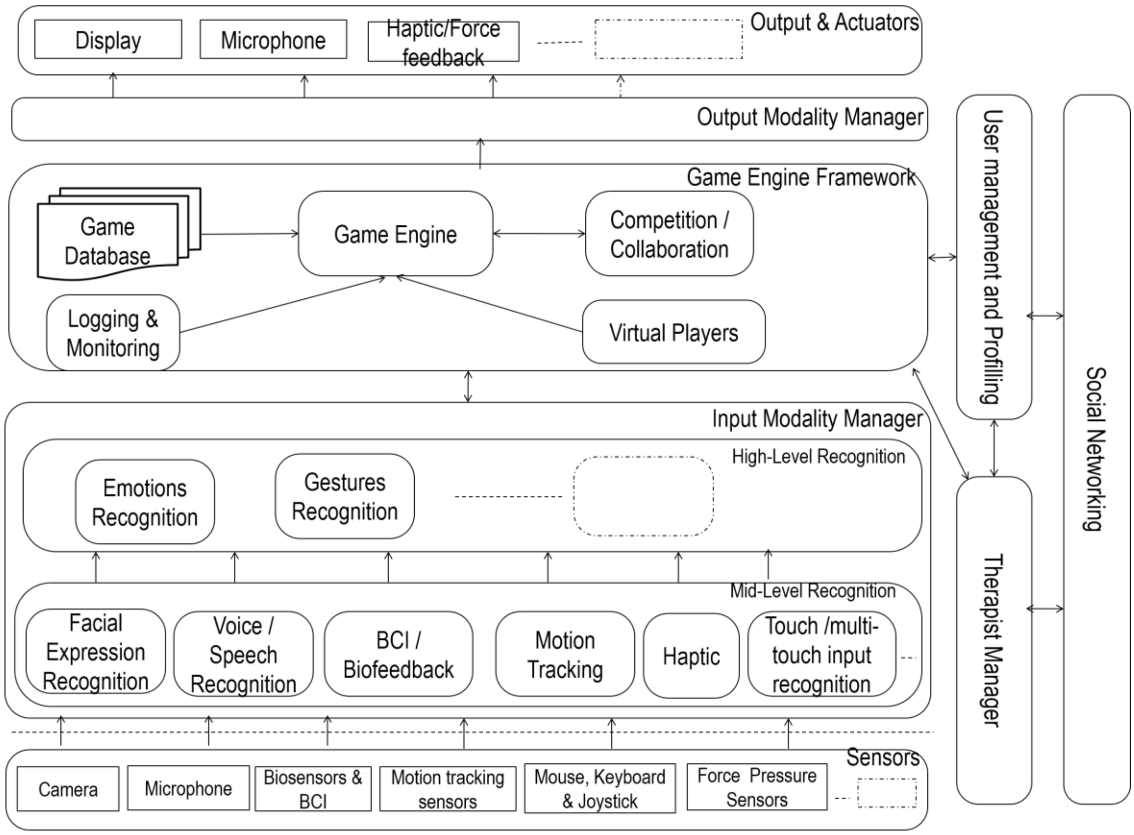


Figure 78 - Proposed Architecture.

In order to support different devices for different Serious Games we consider an abstraction layer between the input devices and the games, which is represented in the figure by the Input Modality Manager. This abstraction layer is used to support multiple input devices, allowing the possibility of using them together in the same game. It will enable the therapist to choose the devices that are best suited to the patient's condition and that better support the specific therapy. The abstraction layer will also allow to avoid conflicts between devices. This abstraction layer can be used thus to support many devices such as: camera sensors (such as the Microsoft Kinect sensor and the LEAP Motion Controller), balance boards (such as the Nintendo Wii Balance Board), and haptic devices (for instance, the Novint Falcon [326]). In physical rehabilitation, Input devices should be useful for tracking/capturing the movements necessary to perform a correct rehabilitation. Microsoft Kinect has been revealed to be a powerful device for rehabilitation purposes that can be used in posture and balance games.

Therefore, in terms of inputs, the proposed architecture comprises several distinct layers of input recognition. The first layer represents input modalities in raw form. The second layer represents an abstract recognition from the inputs received in raw form. In the third layer, we can see a combination/fusion of more modalities among each other: gestures recognition, emotion recognition, representing higher levels of recognition processes.

In the next section, the main modules of the proposed architecture are described in detail.

5.2.3 Framework Modules

Game Engine

The game engine is the game component that is most common to all games, representing the most generic component of the game logic. It is a framework, or a set of tools that supports the developers with the base components for creating a game, such as: physical component, graphics rendering, collision detection, artificial intelligence, sound, and support for different deployment platforms, among others [327], enabling that the developers can focus on the details of each game. The rendering of 2D or 3D scenes is done through graphics engines. The physics engine enforces the laws of physics in the models, taking into account components such as velocity, air resistance and collision detection. The set of modules that compose the game engine allows that when a new game is created, existing game engine functions can be reused. Examples of game engines include Unity and Neoaxis [328], among others. Unity [329] is a popular game and development environment, authored by Unity Technologies, for the production of Web games, desktops, consoles and mobile devices. In addition to numerous advantages, it uses scripting languages allowing to add new functionalities at any stage of development, bringing advantages to applications in the area of rehabilitation. An example of the use of Neoaxis engine is the “Emergency Medical Services for the disAbled” Virtual Environment (EMSAVE) software for training users in emergency medical situations involving disabled people [316].

Game Database

The game database is the most specific component of the games that represents the repository of all the games that are available for use in the rehabilitation session.

Social Networking

This module is responsible for creating the mechanisms for users (patients) to group together in social networks in order to communicate with each other and providing tools to mediate and facilitate social interactions.

Competition/Collaboration

This module is responsible for creating the interaction mechanisms of competition and collaboration among users. It includes user modelling and profiling for establishing the handicaps with which each user will play with others, even if at different levels of the rehabilitation process.

User Management and Profiling

This module is responsible for managing the information associated to the users, including their profiles, therapies they have to follow, state of the therapy, progress indicators, handicaps, etc.

Logging & Monitoring

This module is responsible for registering the users' logs, session duration, last difficulty level attained in each session in order to monitor the progress of each patient during the therapy.

Virtual Players

This module is responsible for defining the agents that will assume the responsibility of users/players in the application sessions. This will enable some multiplayer games even with only one real user.

Therapy Manager

This module provides a set of tools to configure, monitor and analyze the configuration of the prescribed therapy: the games that each patient will play, the duration of the sessions, the progress, among others.

Input Modality Manager

This module manages the different input modalities and it can be adapted to the different disabilities of the users. It can be decomposed in two levels of recognition: at the mid-level we have individual forms of recognition: facial expressions, voice/speech, BCI/Biofeedback, motion tracking, Haptic and Touch/multi-touch.

At a higher level we can have a fusion of some of the mid-level modalities with, for example, a module of emotions recognition and/or a module of gestures recognition. Machine interpretation of human behavior is very important in HCI to achieve natural forms of interaction.

At the mid-level recognition, users can communicate or interact with the machine by several forms that need to be interpreted by the machine. Users can convey messages in the form of body gestures, facial signals, speech, and emotions, among others. At a higher level of recognition, gestures recognition systems can have a multimodal nature, representing a fusion of the different mid-level input modalities. Gestures can be translated via hand gestures, or by body positions and movements (that control a virtual environment on the screen), being captured by cameras, or by the use of data sense gloves; alternatively, the gestures can be face gestures, or a sequence of finger positions and movements in a multi-touch table. Emotions are also multimodal - they can be expressed through several modalities (and channels) of the mid-level recognition module, for example, verbally by the use of emotional vocabulary, or by expressing several non-verbal cues such as facial expressions, voice intonation, postures, gestures, and physiological changes. The decoding of these cues is essential to interpret the correct message. It is therefore necessary in a multimodal system to make a fusion of these different modalities to achieve a reliable (accurate) assessment;

Output Modality Manager:

This module manages the different output modalities. The interface can include a display, sound device, haptic device and force-feedback equipment and it can be adapted to a specific game, environment or user.

5.2.4 Summary

This architecture proposal can implement a social network or connect to third-party social networking services. It foresees the development of virtual player and competition/collaboration modules, the integration with the social/users community component, the development of the input/output modality component and the introduction of more natural modalities of interaction in the modules of competition/collaboration. Proof of concept games were developed and will be presented on the next chapter based on the described framework.

Other modules specific to games such as a score system and a reward system could also be included as well in the proposed architecture. During gameplay, or in-between games, the patient has to interact with the game system through the interface (via a menu system) that can be used to check his progress, and to choose games. Thus, a score and a reward system could be associated to the results of the games, and used to show to the patient his progression. A module that provides the methods to implement the variations inside the games and in the reward system would also be necessary. Configuration and Performance assessment (which would not be automated) would be connected through the internet to the therapist that can be at a hospital or clinical.

5.3 Related work

In this section, we refer some work with similar objectives published by other authors.

Parallel to our ongoing work, we have been identifying other works that share the same objectives and identify similar questions for study [70, 75, 82, 201, 274, 330, 331]. Some of these researchers present a multimodal architecture for motor and cognitive rehabilitation, including facilities for social interaction and multiplayer games. Most of these systems do not consider the inclusion of virtual agents (except Pirovano et al. [331]), and do not foresee the inclusion of handicap mechanism in the games. Omelina [274], for example, presents a multimodal architecture that focuses neuro-muscular rehabilitation and does not foresee the inclusion of facilities for multiplayer games. Conconi et al. [70], Kocsis et al. [330] and Kostoulas et al. [201] present a 3D game environment for facilitating the development of Serious Games as part of the European project Playmancer. Playmancer contains a multimodal dialog manager that enables the inclusion of multiple interaction modalities.

Pirovano [331] designed and implemented an architecture for the development of games for physical rehabilitation – exergames, which supports multiple devices, natural interfaces, competitive and collaborative games and autonomous supervision (monitoring and adaptability). It includes a therapist avatar that explains the correct motions and presents summaries of the results to the patient and serving as a motivator in the rehabilitation session, such as a real therapist will do in a traditional rehabilitation session.

5.4 Summary

This chapter provided an overview of the main requirements regarding the design and development of Serious Games for Health Rehabilitation followed by the presentation of an architecture proposal for the development of the games, based on the requirements previously described, and including its main motivation and a description of its main modules.

It also presented some related work published in the literature that share similar objectives.

Chapter 6

Games' Implementation

6.1 Introduction

In this chapter, we present the main implementation details concerning the games developed throughout this project in order to study and test the thesis statement.

6.2 Preliminary Work: Motion Detection Prototype

Initial work related with the thesis project was done during the curricular component of the Doctoral Program in Informatics Engineering and includes the design, implementation and testing of a serious game prototype [332] developed in order to evaluate the effect of the introduction of new forms of interaction in rehabilitation serious games. The description herein presented of the prototype includes its objectives, game concept, game interaction technology and implementation. The user testing [332] of the implemented prototype and a comparison with the systems that were reviewed in Section 2.3.2 is presented in chapter 7.

6.2.1 Objectives

To study if the use of more natural forms of interaction and serious games can augment the efficacy of the rehabilitation process, by increasing the motivation of the patients in the therapy sessions, we choose one of the games from the system RehaCom, to design and implement and introduce to it new forms of interaction. The game prototype developed can serve as a proof-of-concept application to investigate if these new forms of interaction can be applied to increase motivation in rehabilitation patients.

6.2.2 Game Concept

RehaCom is composed of a set of serious games modules (for executive function, memory and attention training, among others) and was found to be a reference system in rehabilitation serious games, for cognitive rehabilitation [98]. “Memory for Words” was the game chosen from RehaCom system, included in the “Memory Training” category of RehaCom modules. The game goal is to recognize a set of words that were memorized in a first (learning) phase and that after appear in a sequence of other words. The interface of the game is two-dimensional.

6.2.3 Game Interaction Technology

In RehaCom “Memory for Words” game the words were chosen by the user using the special panel, the mouse or a touch screen. Our implementation of the game considers three forms of input: using the mouse (mouse detection), using some noise (sound detection), or using some motion (motion detection). Figure 79 shows the screen interface of our game that is presented to the player asking him to choose from one of these forms of interaction. Figure 80 presents some screenshots of the game play. The hardware required to run this game prototype consists of a laptop or computer desktop with internet access, a microphone and a webcam.

Figure 79 - Screen interface of the game asking to choose the input option.

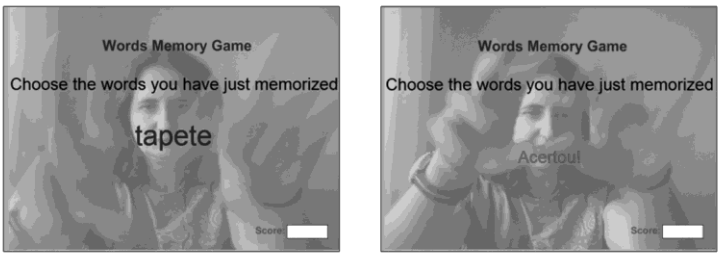


Figure 80 - Screenshots of the game play.

6.2.4 *Game Implementation*

The prototype was implemented in the Adobe Flash platform, using the ActionScript 3.0 programming language. Adobe Flash allows to work with the sound captured from the microphone attached to the computer using the Microphone class which returns the current activity level of the microphone [333]. Video input is handled through the Camera class which allows to detect levels of motion and to make the stream of the captured data over the network, or locally to an instance of the Video class which makes the display of the data [333]. This allows also to analyze images pixel by pixel and to implement image processing and computer vision filters.

The possibilities of the Flash ActionScript API are encouraging as it provides, besides an OOP language, a rich and complete set of classes devoted and oriented to develop interactive, interconnected and rich-media applications. There are already third-party libraries and frameworks that extend these capabilities with more elaborated tools to handle for instance face recognition tasks - such as the Marilena [334] port of the OpenCV [335] object recognition, the FlARToolkit [336] - a port of the disseminated ARToolkit [337] for Augmented Reality, PaperVision3D [338] to handle three dimensional object representations such as virtual worlds and TUIO AS3 Lib – a library that implements the TUIO [339] framework for tangible multi-touch surfaces.

Figure 81 presents a block diagram of the specific architecture of the system. The detection modules (mouse, sound and motion) have functions to prevent the detection of two levels of consecutive sounds. They also include functions of calibration of the recognition modules to be adjusted to the environment conditions like the background noise level and/or lighting issues.

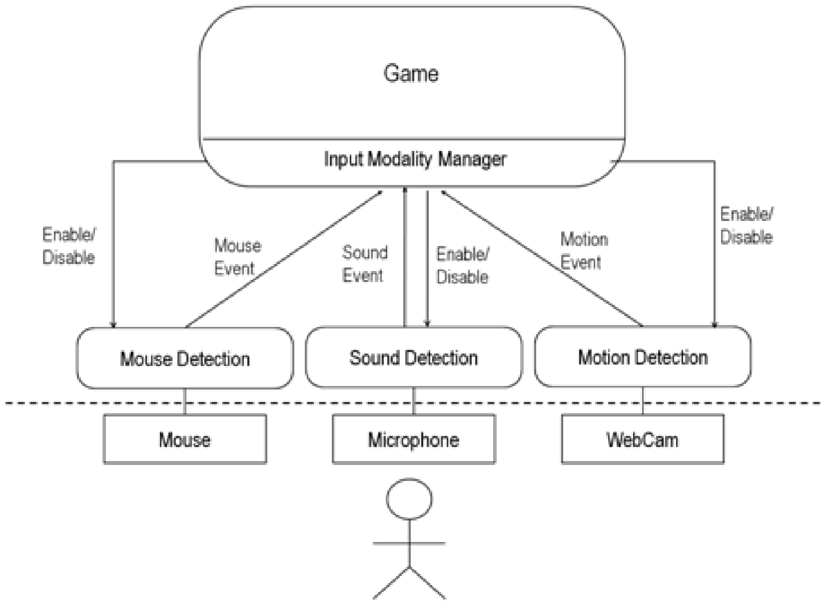


Figure 81 - Representation of the main modules of the prototype system, with particular detail on the input modalities

Adobe Flash provides classes that allow basic mechanisms to activate the detection of some specified level of sound and/or motion.

In the sound input option of our game, the detection of a player's action is achieved by checking when the activity level reaches a certain threshold. The approach in our motion input option game consisted in sampling a sequence of activity levels and use these and a threshold value to decide if an option/word was selected.

With the sound and/or motion interaction, one of the problems is that the game velocity is limited by the detection process itself. With a sound or motion interaction, a user cannot play as quickly as it would if he was using mouse clicks.

In the developed prototype, the three modes of interaction (mouse, sound and motion) can be enabled and activated at the same time. However, for the purpose of the current study, the actual configuration uses only one mode of the interaction at a time, which the user chooses in the beginning of the game.

6.3 Rehab+ Platform

A Web platform comprising a set of games adapted for use in cognitive rehabilitation has been developed. In this way the game can be played online, making it more accessible to all users, including patients in rehabilitation. Besides that, the web platform provides a low cost solution to patients training and eases a home rehabilitation, in addition to traditional therapy.

In this section we describe the solution architecture of the Rehab+ platform, the games that are part of it and the technologies used in its creation. The tests carried out in the validation are described in chapter 7.

6.3.1 Solution Architecture

The design of rehabilitation characteristics is a complex task. First, because it depends on the limitations of each patient but additionally because it must be made effective by a multidisciplinary team composed of professionals from various fields such as psychologists, physicians, and therapists, among others.

In this investigation, several innovative features were proposed whose main objective was to increase the motivation of patients during the rehabilitation process. These features were designed to make games more motivating, attractive and easy to interact, by using a natural user interface and incorporating social characteristics, in particular: competition, collaboration and the concept of handicapping.

The first step in the development of Rehab+ consists in defining features to be included in each of the games developed. In this work, we decided to develop the games of the Rehab+ platform with similar rehabilitative features to an existing and established set of rehabilitation games that compose the RehaCom software [86, 87], and provide the Rehab+ games with the features proposed in our investigation. The RehaCom software, used for computer-assisted cognitive rehabilitation in many hospitals and rehabilitation centers around the world, provides a set of games, divided in training modules, to improve the cognitive functions (such as attention, concentration, memory, perception, activities of daily living, among others).

It was decided that each game should contain rehabilitative features capable of stimulating at least one cognitive function, as well as some of the features we proposed in this research as a way to improve the motivation of patients in rehabilitation. These features include the use of natural user interfaces, the use of social features as competition and collaboration, and the introduction of a handicapping mechanism.

Additionally, in order to verify the existence of different reactions of individuals when faced with games that provide the proposed features, and other games that do not offer them, a game was developed that does not provide any of the proposed features, and another version of the same game that includes some of them.

The Rehab+ platform comprises all the games developed, providing the solution that integrates all of the games in one place. This platform groups the games in two categories: single player and multiplayer. Figure 1 presents the simplified diagram of the Rehab+ platform, providing an overview of the integration of the proposed features in several developed games.

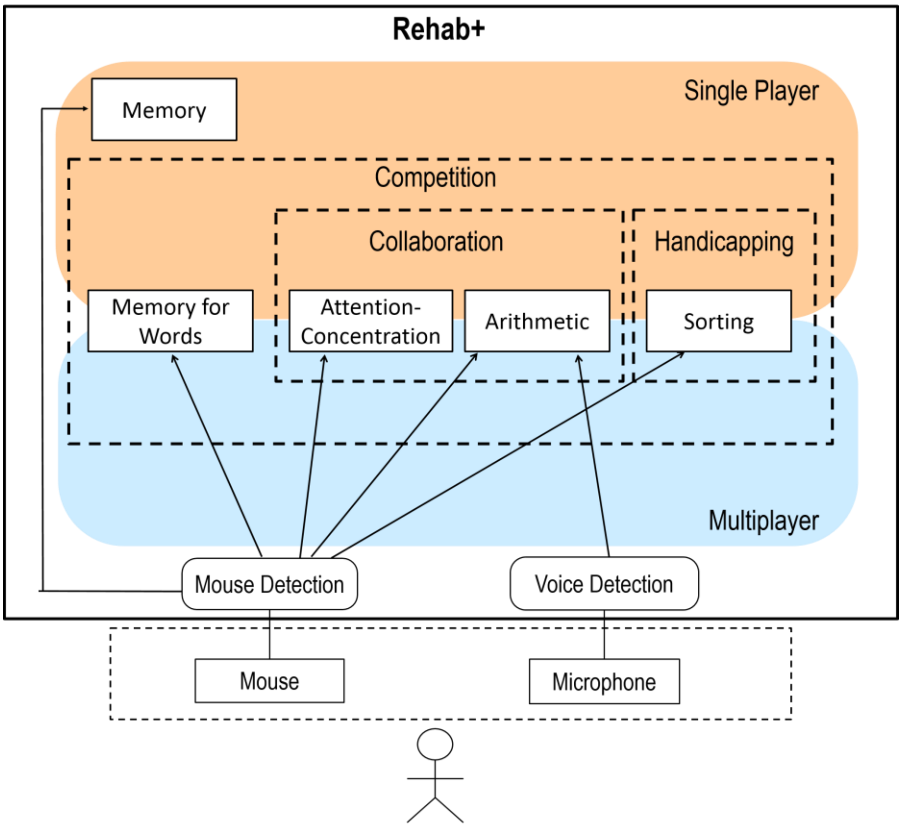


Figure 82 - Simplified Diagram of the Rehab+ Game Platform.

Twelve games were developed that include different approaches to the same game: memory, sorting, arithmetic, memory for words and attention-concentration. For example, in the single player category/approach the games included are: memory, sorting, arithmetic (using mouse), arithmetic voice (arithmetic using voice commands), memory for words and attention-concentration. In the multiplayer category/approach the games included are: arithmetic Collaborative (arithmetic using a collaborative approach), sorting multiplayer (competitive mode), sorting handicap (sorting multiplayer competitive using handicap mechanism), memory for words multiplayer (competitive mode), attention-concentration multiplayer competitive and attention-concentration multiplayer collaborative.

The memory game does not include any of the proposed features and is only available in single player mode. The sorting game, available in single player and multiplayer, covers competitive features and a handicapping system. The arithmetic game is available both in single player, and in multiplayer version, the later version being based on collaborative features, and the single player version also has the possibility of interaction using voice recognition. The memory for words game is available in two versions: single player and multiplayer competitive. The attention-concentration game is available in three versions: single player, multiplayer competitive, and multiplayer collaborative. All the games have interaction via mouse or via a touch screen.

6.3.2 Integrated/Implemented Features

In this investigation, several innovative features were proposed whose main objective was to increase the motivation of patients during the rehabilitation process.

These features were designed to make games more motivating, attractive and easy to interact, by using a natural interaction interface and social characteristics, in particular: the competition, collaboration and the concept of handicapping.

In the games developed for this research we tried to incorporate in the best possible way, the proposed features to meet the initial objectives. As such, these games include all the features proposed.

The games developed follow a competition and collaboration approach, and include a natural user interface to control the game (in this case, using voice commands). It was also implemented a handicapping system in two games.

Next, we detail the main features proposed and implemented as part of the developed Rehab+ platform of Serious Games.

User interface

All games developed enable interaction via a mouse or via a touch screen, if they are used in mobile devices. The use of this type of games should foresee possible motor difficulties for users. In this sense, it was included in one of the developed games an alternative mode of interaction. With the use of a JavaScript library and the Google Chrome browser it is possible for users to interact with the game “arithmetic voice” (Cálculo Voice) through voice commands, thus adapting the game to different profiles of users with varying abilities and difficulties/limitations and thus exploring the concept of multimodality. This form of interaction by voice commands also requires the use of a microphone. This type of natural user interface also allows users to interact with the system without the need to use an external device to the computer, since the built-in microphone on most laptops is sufficient to ensure a stable interaction. The major limitation of this user interface relates to its use in environments with a lot of background noise, making it difficult a correct detection of the necessary voice commands. In addition, it requires the use of a browser that allows voice interaction, which limits the choices for users and may require the installation of specific software. However, of the most used browsers on the market, Google Chrome is the only one that allows this type of interaction, and is also the most used browser worldwide [340]. Despite its use being an obligation in this case, it does not however require a major effort for learning and getting used to it, since all the various existing browsers currently have a very similar operation.

In some of the games, we had to make modifications to the interface after prototyping and testing with elders, mainly in Memory for Words Game where we had to increase the fonts size and to diminish the speed of the game in showing up the several screens of its execution. We tried to focus on accessibility showing a clear and simple graphical design with clear and immediate feedback, maintaining a clear and common style along the several games to avoid introducing visual noise.

We also make use of NUIs in one of the games both for navigation and for the gameplay. The difficulty of the games is adaptable to the patient’s performance.

Collaboration/Cooperation

Cooperation characteristics are part of a social approach to this kind of games, which aims to promote increased interaction between patients. Our proposed hypothesis is that this type of features enables patients to increase their motivational levels in relation to games and the rehabilitation process, from the companionship of their peers that are using the same games they too use. In this particular case, it is expected that, due the fact that patients are playing as a team, they will interact more, communicate more with their peers and create social bonds with their teammates, trying to avoid their isolation. These features were incorporated into the arithmetic game and were designed so that each user has a role in the completion of the task. Thus, each user plays a specific role to be played so that both can attain success as a team.

Competition and Handicapping

A competitive game approach exploits similar concepts to those of collaboration, in the extent that is expected that patients will be motivated by sharing their experience with their peers. The characteristics of competition assume that two users are confronted for reaching the best individual result, not acting as a team but as opponents. It is therefore important to address the disparity difficulties of several patients. Different patients can have different problems and different types of limitations, and therefore when they confront themselves in these conditions, it is complicated, unfair and not motivating for them, which would prove to be contradictory to our purpose of the inclusion of these features. Thus, the concept of handicapping can be used in these situations since it seeks to equalize opportunities to win for each user. For example, in the multiplayer version of the sorting handicap game, system checks of the levels at which each user is are performed. If the user is playing a level above his opponent, the system makes the numbers to sort a second longer to appear than the numbers of his opponent. When the level difference is greater than two, the user that is in advantage receives only half of the bonus value whenever he completes a level.

6.3.3 Graphical Interface

A Web platform comprising a set of games adapted for use in cognitive rehabilitation has been developed. In this section we describe the development process of this solution - the Rehab+ platform, presenting its graphics interface, the main features implemented in the games and the technologies used in its implementation. The project and implementation had the collaboration of Rui Rocha [91, 341-344].

The Rehab+ platform houses all the games developed during this work, providing the solution that integrates all of the games in one place. This platform groups the games in two categories: single player and multiplayer.

Figure 1 presents the graphical interface of the Rehab+ Game Platform, providing an overview of the integration of the features we proposed in several developed games. Five base games were developed: memory, sorting, arithmetic, attention-concentration and memory for words.

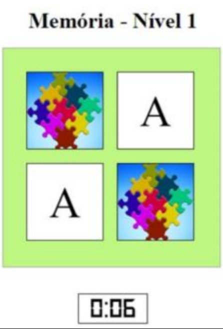
The memory game does not include any of the proposed features and is only available in single player mode.

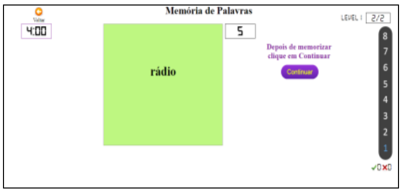
Figure 83 - Rehab+ Game Platform graphical interface

The sorting game, available in single player and multiplayer, covers competitive features and a handicapping system. The arithmetic game is available both in single player, and in multiplayer version, the later version being based on collaborative features, and the single player version also has the possibility of interaction using voice recognition. All the games have interaction via mouse or via a touch screen.

Table 15 presents a list of the developed games, presenting for each game some of their characteristics: graphic interface, main objective of the game in rehabilitation terms, interaction technology used and social features that were implemented.

Table 15 – Rehab+ games characteristics.

Memory game  	**Main objective** of the game is the training of working memory or short-term memory (vision) and sequential memory	**Implementation:** only single player version user interaction via mouse no competition no cooperation no handicapping
Sorting game  	**Main objective** of the game is the training and encouragement of the reaction times of users, concentration, reasoning, memory and sequential processing, spatial perception, visual processing and attention	**Implementation:** single player and Multiplayer (2 players) user interaction via mouse competition ☑ handicapping☑ (in Multiplayer version)

Arithmetic game  	**Main objective** of the game is to improve the mental calculation ability, numerical reasoning, and problem solving	**Implementation:** single player and multiplayer (2 players) user interaction via mouse and voice commands collaboration ☑
Memory for Words  	**Memory Training** **Main objective** of the game is the improve memory for verbal material through the exercising of recognition capabilities. In addition, it requires continuous attention from the patient.	**Implementation:** single player and multiplayer (2 players) user interaction via mouse competition ☑
Attention- Concentration  	**Attention training** **Main objective** of the game is to train simultaneously abilities to differentiate and to concentrate.	**Implementation:** single player and multiplayer (2 players) user interaction via mouse competition ☑ collaboration ☑

6.3.4 Games Implementation

The developed serious games have been designed to run in browsers, so its implementation was based on the use of the programming languages JavaScript, HTML and CSS. Since the games have been thought to be integrated into a web perspective, we opted for a language that would allow its easy dissemination between different platforms. With the development using these web languages, supported by all browsers, games can be used in virtually any device with internet access such as tablets and smartphones.

The web pages where the games are integrated were coded using HTML and the visual formatting of pages and games was worked using CSS. All the mechanics of the games was implemented in JavaScript, that is, all code developed that ensures the operation of the games. We also used PHP, AJAX and SQL to provide the games with the functionality to keep records of their results in a MySQL database, to enable the progress monitoring.

Multiplayer games were designed to run on a single machine, in the same browser window. The interaction in multiplayer games is achieved through a mouse, so it was necessary to use a specific software to allow that two users do not have to share the same mouse. During this investigation, this has been achieved using the software "Team Player 2.2 Multi User". This software is one of the few alternatives on the market that has a free license, is also lightweight and easy to use. Its purpose is to have more than a mouse to operate simultaneously and independently on the same computer. After installing the software, it must be ensured that all necessary mice are connected to the computer. Verifying this assumption, we just run the software and the computer is able to use all mice connected simultaneously and independently. The software is therefore easy to use and extremely functional. In this investigation, only two mice were used simultaneously, and both work smoothly. The distinction of mice is very intuitive, since the software assigns a different color to each of cursors (Figure 84). The only limitation found are small competition problems that occur sporadically when two users try to click at the same time something that is on the screen. This limitation did not cause significant problems during the testing phase.

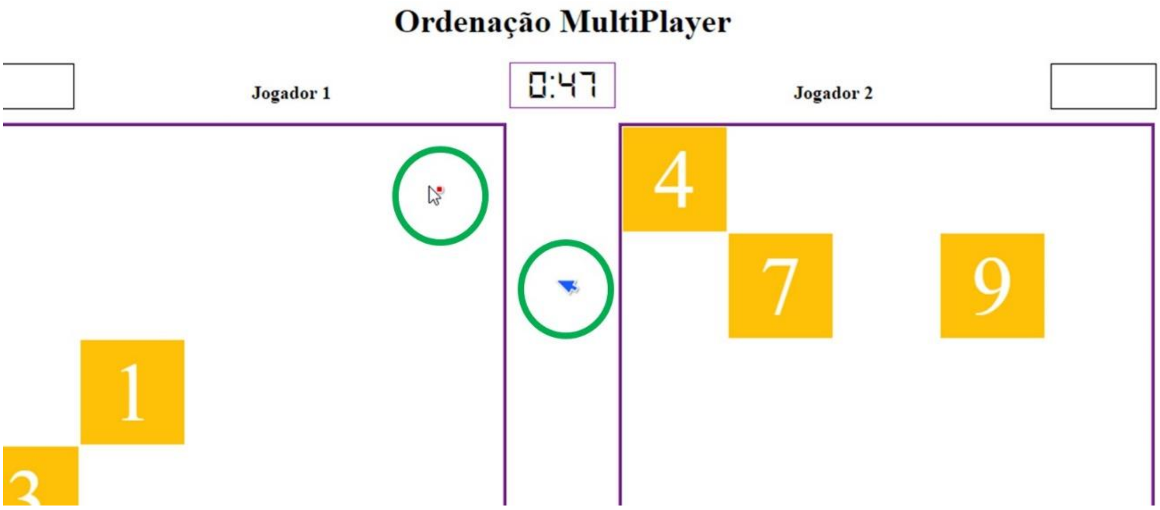


Figure 84 - Graphical interface of Sorting game showing the cursors of two mice.

During the development of the games an interaction interface based on speech recognition was implemented. For this a JavaScript library of voice recognition, called Annyang [345] was used, which allows the user to interact with the game through voice commands.

This library uses a JavaScript API, called Web Speech, which allows, among others, to use the voice as a means of interaction/ control of web pages and to convert text into speech. The use of this API, in conjunction with voice recognition capabilities integrated in Chrome browser, make this library a lightweight tool, easy to use and a tool that fits for the intended approach to this type of interaction interfaces. This library supports multiple languages, including Portuguese, used in this research. Additionally, it weighs only 2kb and its use is freeware.

Google Chrome browser lets interact with any microphone that is connected to the computer. In turn, the Annyang library allows to work the captured sound and use it as commands that are used to control the actions of the game. The first step is to load the Annyang.js file to the page where the voice control will be used. Then, the set of commands needed in the game must be defined and the functions must be configured with what should happen in the game, when the voice command is detected.

6.3.5 Implemented Games

We developed a web platform composed of a set of games adapted for use in cognitive rehabilitation. In this section we describe in detail the serious games implemented as part of the Rehab+ platform.

The serious games developed were designed to run in browsers, so its development was based on the use of JavaScript, HTML and CSS programming languages.

It was defined that each game should contain rehabilitative characteristics capable of stimulating at least one cognitive function, as well as some of the characteristics proposed as a way of improving patients' motivation in relation to the rehabilitation process. Thus, games implemented include the set of proposed features. Among these characteristics, the multimodal interaction interface, supported by a natural approach (NUI), stands out. A social aspect was also introduced, based on the concepts of collaboration and competition. In this way, the developed multiplayer games were based not only on the competition between users, but also on a perspective of team play. The competitive aspect was further reinforced by the introduction of the concept of handicapping, which aims to ensure balance among users, and is designed to compensate users who may be at a disadvantage, as in the case of patients with different physical and cognitive limitations.

During this research were developed 12 games, including different approaches to the same game, for example single player and multiplayer version, covering various cognitive abilities such as memory, mental calculation and attention and concentration, among others. Two distinct forms of interaction were exploited: voice and mouse. In one of the games collaborative social features were incorporated: three games exploit the competition aspect and one of these has implemented a handicapping system. Table 16 presents the main base games that were implemented, grouped according to the main cognitive function that is stimulated. In the next section, we describe in detail their implementation.

Table 16 - Main base games grouped according to main cognitive function stimulated

Game	Main Cognitive function stimulated
Memory (Memória)	Training of memory
Sorting (Ordenação)	Executive Functions
Arithmetic Game (Cálculo)	Executive Functions
Attention-Concentration (Atenção)	Attention Training
Memory for Words (Memória de Palavras)	Training of memory

6.3.5.1 *Memory Game*

The main objective of this game is the training of working memory or short-term memory (vision) and sequential memory. This game was developed only in single player version, and does not include any of the features proposed in this research. The interaction with the game is done by a mouse.

The game consists of a main board which contains an even number of cards face down. Below each of the cards is a letter. The arrangement of these letters is defined randomly. The player must click on the cards to see the hidden letters and to find all pairs. The game has eight levels, that are progressively more difficult. The first level consists of four cards and has set a maximum time of completion of ten seconds. The difficulty level is based on two premises. Firstly, each level has a maximum time to complete and throughout all levels the number of cards in the board progressively increases, at a rate of two letters per level during the first seven levels. The last level is thought to be more difficult and has 24 cards. It was estimated a temporal increase of five seconds for every increase of two cards. At each stage of the game a chronometer is presented to the user indicating the time available and a progress bar where the user can check the level he is in, and the remaining time to finish the game. The game is only considered complete when the user finishes all levels. Whenever a user repeats a level the timer resets and the letters are arranged randomly again. Figure 85 presents the graphical interface of the memory game.

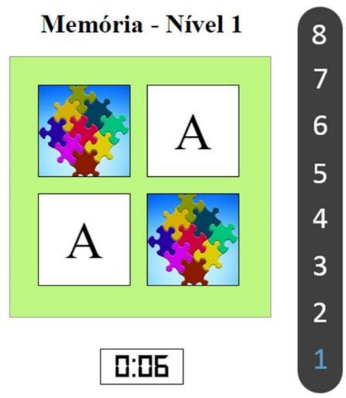


Figure 85 - Graphical interface of Memory game.

The game uses simple, two-dimensional graphics and suggestive images to give feedback to the user about the completion with or without success in each level. This game does not use any sound or sound effect and interaction is based on a point-and-click interface.

6.3.5.1 *Sorting Game*

The main purpose of this game is the training and stimulation of the reaction times of users, concentration, reasoning, memory and sequential processing, spatial perception, visual processing and attention. This game features a single player and multiplayer version, for two simultaneous users, and includes features of competition and handicapping. To this end we developed three different versions: Sorting, Sorting Multiplayer, and Sorting Handicap. In all these versions the interaction is made through a mouse. During the testing phase of the multiplayer versions, we used the "Team Player 2.2" software developed by WunderWorks [346], which allows the use of several mice simultaneously on the same computer. This version of the software has a freeware license of use. The game uses simple graphics (Figure 86) in two dimensions and images to indicate the conclusion of the game and the end of the time available to complete it. This game does not use any sound or sound effect and interaction is based on a point-and-click interface.

The objective of this game is to sort the numbers that appear on the screen. There are two possibilities. In the game window are presented several squares with numbers inside. The square may have two colors, blue or orange. If the squares are blue, the user must click on each of them in ascending order of their numbers, if they are orange then the user has to repeat the same process but in reverse order, that is in descending order.

Figure 86 - Single player Sorting game.

The single player version of the game begins with the provision of three different numbers, each inserted in a square. The way these numbers should be ordered is always set at random, as the numbers themselves, ranging from 0 to 9, and the position on the screen every square occupies. In this version the user has one minute to complete all levels.

When a user misses the square where he should click the level is restarted with new random numbers, new way of ordering and new positions to the square. The game ends when the last level is completed, which includes all the numbers from 0 to 9, or when the timer expires. The game is considered complete only when the user successfully completes all levels. The user has always access to a visual indication of the time available to complete the game.

In this game there is no indication of the level neither of how many levels are missing to complete. This option is due to the fact the game is of faster nature and there is not a specific time to complete a level, but the full game. Each new level starts immediately after successful completion of the previous.

The multiplayer version of this game is based on the same basic principles of the single player version of the game. The main difference at visual level is the introduction of a new game window thus providing two game boards, one on the left side of the page, the other on the right side. In this version users have ninety seconds to complete the maximum possible levels. Unlike the single player version there is no maximum number of levels, the board is renewed every time the user completes a level successfully and always with the increase of a number to be ordered in relation to the previous level. In this version a scoring system was implemented so that at the end of time one can determine the winner. So whenever the user clicks on a square in the correct order he wins five points, and if he clicks a wrong square he loses the points equivalent to the level.

Handicapping

The handicapping system was implemented in the multiplayer version of this game. This mechanism aims to level the hypotheses of both participants to win the game and was specifically designed to make the game more difficult for the user who is winning. It works in three phases and in accordance with the greater or smaller difference between opponents. The system performs system checks of the levels at which each user is. If a user is playing a level above his opponent, the system makes its square linger a second longer to appear than the square of his opponent. When the level difference is greater than two, the user that is in advantage receives only half of the bonus value whenever he completes a level. This system was thought to be adaptive and respond according to particular characteristics of each game / player.

Collected Data for Progress Monitoring

In the current implementation, the game records the following data:

- For each task (position) the game records:
    - The task id (`taskLevel`): a sequence identifier for the task
    - The level id (`level`): the identifier of the level
    - A flag indicating if the task was solve correctly (`acertouTask`)
- For each level the data recorded is:
    - Level id (`level`)
    - Seconds registered in Countdown timer (`seconds`)

- The number of positions that the user correctly chosen in the actual level (`certasNivel`)
- The number of positions that the user incorrectly chosen in the actual level (`erradasNivel`)

- For the game data recorded is:
    - An id for the game (`jogo`): is a string identifying the game;
    - Game Levels: the maximum number of levels in the game
    - Finished Level: the last level that the patient completed
    - Total Time of the game
    - Game score (`scorej1`)
    - Level Tasks: the number of tasks for the level (assuming that is constant for the game)
    - Flag indicating if the user ended the game before time limit
    - Flag indicating the reason the game end: 1- User, 2 – time limit
    - Total Tasks of the game
    - Total of correct decisions in the game
    - Total of incorrect decisions in the game
    - Total of levels solved incorrectly (`niveisErrados`)
    - Total of levels solved correctly (`niveisCertos`)

In the multiplayer version, the game records additional data about the second player regarding that it has one more player.

6.3.5.2 Arithmetic Game

This game aims to improve the mental calculation ability, numerical reasoning, and problem solving. The game presents simple plots (Figure 87), and two-dimensional images that indicate whether the level has been successfully completed, and the end of playing time. This game does not use any sound or sound effect and the interaction with the same features two modes of interaction: mouse, through a Point-and-Click interface, and voice through speech recognition. This game was developed in single player and multiplayer mode, and the latter has collaborative features.

The objective of this game is to perform a number of mental calculations. The game window is divided into two parts; the left side shows the calculations to be performed, and in the right side the correct answers are provided. Several incorrect answer options are also presented, and these options are always values close to the correct answer (one or two values above or below) and are also included random values as a response option.

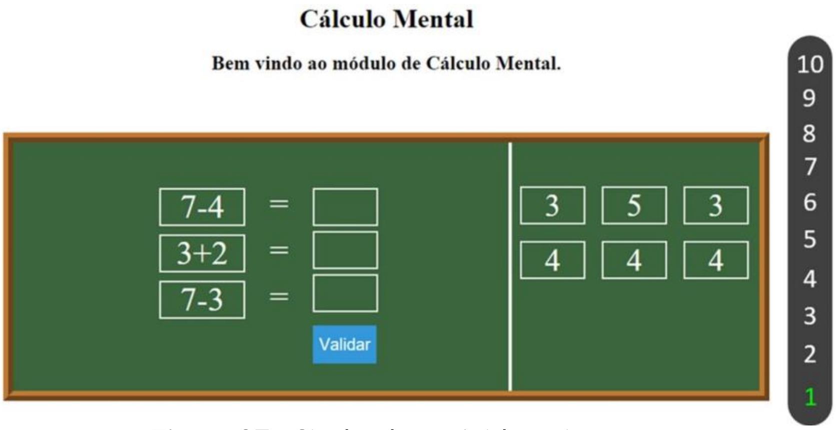


Figure 87 - Single player Arithmetic game.

The user must choose the correct answers to each of the operations. After selecting the answers, the user can proceed to validation. If any is wrong, he receives this indication, since the incorrect answer turns red. While has time available, the user can exchange the wrong answers until he finds the correct one. It is considered one successfully completed level when the user hits all the answers.

This game consists of ten levels and at each level are included arithmetic operations of addition, subtraction and multiplication. In the first four levels, all operations have only two terms and thereafter and until the seventh level, the operations start to have three terms. During these first seven levels, the operations presented to the user never have a negative solution, and in operations with three terms, the second operator is never the multiplication operator, so as not to force the user to apply the priority rules of arithmetical operations. Before starting the last two levels, an information message is displayed to users (Figure 88), which alerts and explains two mathematical rules: the rule of the signs and the priority rules of arithmetic operations. The last two levels have three-term operations, may have negative results and the multiplication operator can appear in any position.

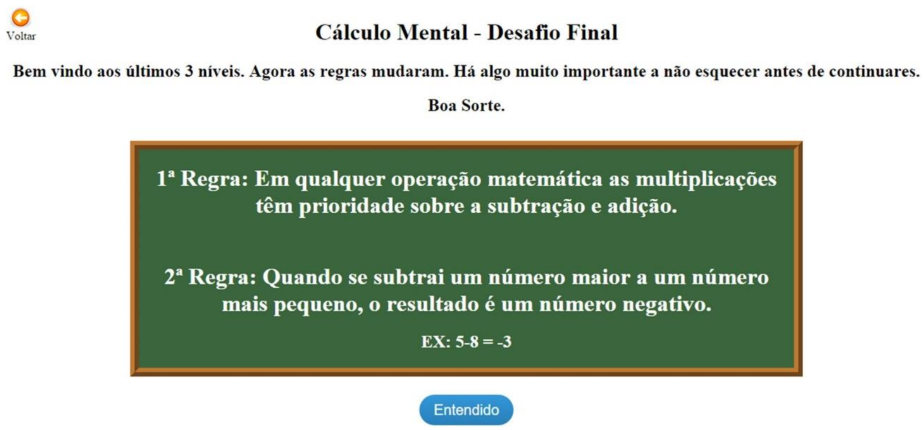


Figure 88 - Information display in arithmetic game.

Throughout the game, the difficulty is gradually increased so that initially the change of the game level is accompanied by an increase of an operation to be carried out, and after by passing from operations with two terms to three terms and finally with the inclusion of operations with negative results and the need to use the priority rules of arithmetic operations. The game ends when the user successfully completes the ten levels.

This game features an alternative modality of interaction, using voice commands. In this type of modality is used a JavaScript library that allows the recognition of voice commands, and a microphone to interact with the game. The game operation is the same, but there are two visual changes: in this version the boxes where the operations are carried out have a color (Figure 89) associated and on the left side of the window a list of commands that the system supports is available. These colors are used to identify and simplify the process of interaction.

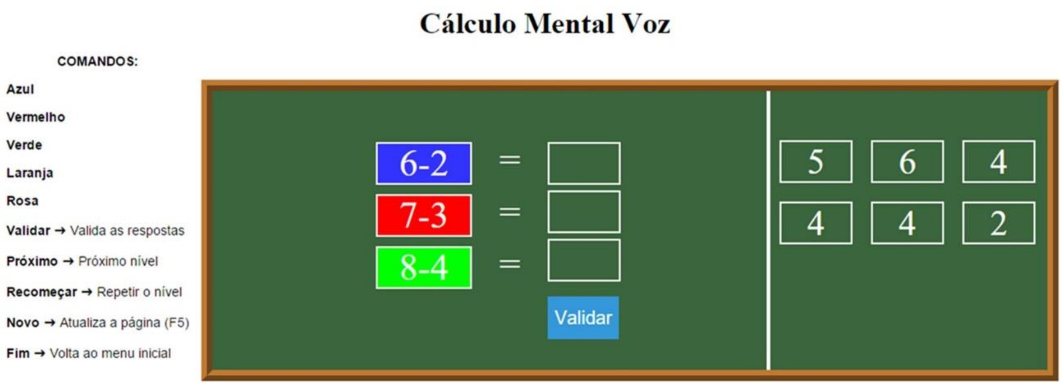


Figure 89 - Arithmetic game – voice input modality.

To select the right answer, the user must say the color that is associated to the operation, followed by his answer (the result of the arithmetic operation), such as: "Blue 4" or "Red 4". To validate an answer is used the command "Validar" (ok). If there are wrong answers, the user only has to repeat the command with the respective color and the new answer. If the time expires, the command "Recomeçar" (Start) restarts the level. When the level is successfully completed, the "Próximo" (Next) command makes the game go to the next level.

Multiplayer Collaborative version

The multiplayer version (Figure 90) of this game incorporates collaborative features. In this respect users play as a team and the mechanics of the game is a little different. Instead of being presented an operation, it is shown a result. Each user must choose which are the required values to add up to reach the displayed result. For this, each user has a set of options for the answer.

These options are different for each user and are presented in two different boards, one positioned on the left side of the window and the other on the right. Each user must choose a value from his side of the board. Users also have a minus sign that can be used in case they select a higher response than the right one.

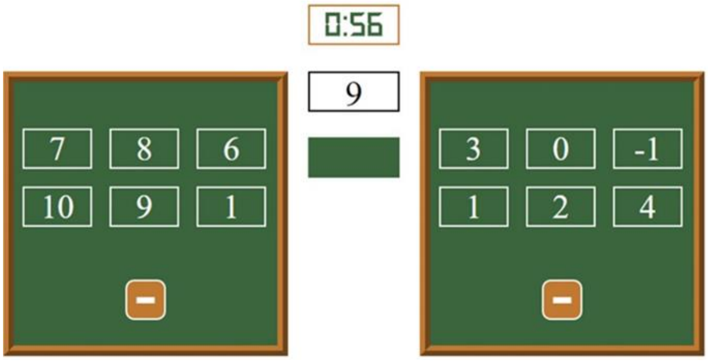


Figure 90 - Multiplayer arithmetic game.

As users will be selecting their answers, the values are being added in a box positioned below the result to be achieved. While they do not reach the correct answer, this box remains red to indicate that the answer is not correct.

When the answer is correct, it is automatically generated a new level with a new random result and new response options. There are not preset levels, the goal is to achieve maximum number of correct results possible within a minute. This game always ends when the minute runs out. In the end, users are informed about how many right answers they reached. The objective of this game is not to identify a winner, but to promote dialogue, interaction and team spirit among the users, promoting social bonding.

Collected Data for Progress Monitoring

In the current implementation, the data recorded is the following:

- For each task (position) the game records:
    - The task id (`taskLevel`): a sequence identifier for the task
    - The level id (`atualLevel`): the identifier of the level
    - A flag indicating if the task was solve correctly (`acertouTask`)
    - The countdown timer in seconds
- For each level the data recorded is:
    - An id for the game (jogo): is a string identifying the gam
    - Level id (`atualLevel`)
    - Seconds registered in Countdown timer (`seconds`)
    - A flag indicating if the level was completed or not (0-incomplete, 1 - complete)
    - The number of tasks in the level (`totalTasks`)
    - Number of tasks solved correctly (`certas`)
    - The number of tasks solved incorrectly (`erradas`)
    - Flag indicating if the user ended the game before time limit (`fimNivelL`)
    - Flag indicating the reason the game end (`eFimNivel`): 1- User, 2 - time limit

In the multiplayer version, the game records additional data about the second player regarding that it has one more player.

6.3.5.3 *Attention-Concentration (Attention Training)*

This game aims to train abilities to differentiate and to concentrate simultaneously. A picture is presented separately in one side of the screen and has to be compared with a matrix of pictures presented on the other side. The patient has to select the one picture that is equal in every detail to the reference picture. This game is based on the Attention-concentration game of RehaCom Cognitive Software System [94].

Training Task

The training screen is divided into two parts. The left part shows the matrix of pictures which may contain: 3 pictures (1 by 3 matrix), 6 pictures (2 by 3 matrix) or 9 pictures (3 by 3 matrix), depending on the level of difficulty that the patient is in the moment of execution.

After the patient selects a picture, the game evaluates the choice as correct or incorrect and indicators on the screen showing the total right and total incorrect answers for that level are updated with the result of these evaluation.

We adopt the term “game task” used in RehaCom Cognitive Software System to refer to the presentation of the matrix of pictures, the selection of a picture and the evaluation of the selected option (choice of the patient).In this way we can say that a level is composed of several predefined tasks (exercises). The number of tasks per level is a parameter of the game, which can be predefined.

The actual version of this game is defined for 8 levels and each level has 3 tasks. The number of game levels and the task levels can be parametrized. In current implementation, a time limit of 2 minutes is defined to play the game.

Interaction

The game starts with an explanation of what the patient has to do on the next screen, as is illustrated in Figure 91.

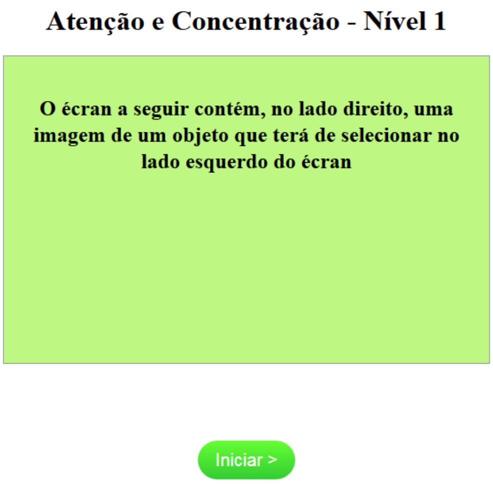


Figure 91 - First screen of the Attention-concentration game (single player)

After clicking on the button "Iniciar", the training screen appears. The game presents simple plots (as illustrated in Figure 92), and two-dimensional images that indicate whether the level has been successfully completed, and the end of playing time. This game does not use any sound or sound effect and the interaction is done via mouse, through a Point-and-Click interface.

This game was developed in three versions: single player, multiplayer with competitive features, and multiplayer with collaborative features.

Figure 92 - Attention-concentration Game at level 3.

Performance Feedback

In the actual version of this game we do not signal the solution of the task by the patient (correct or incorrect) with a message text or with a image indicating that. The task is evaluated and is followed by the presentation of the new task. However, each training screen has information about the task (through an identifier) that the patient is resolving, the number of tasks of the level, the information of the actual level, the number of correct decisions in the level and the number of incorrect decisions as illustrated in Figure 93. Any time the user resolves a task in a correct way those information indicators are updated in the screen.This information is therefore always present in the screen.

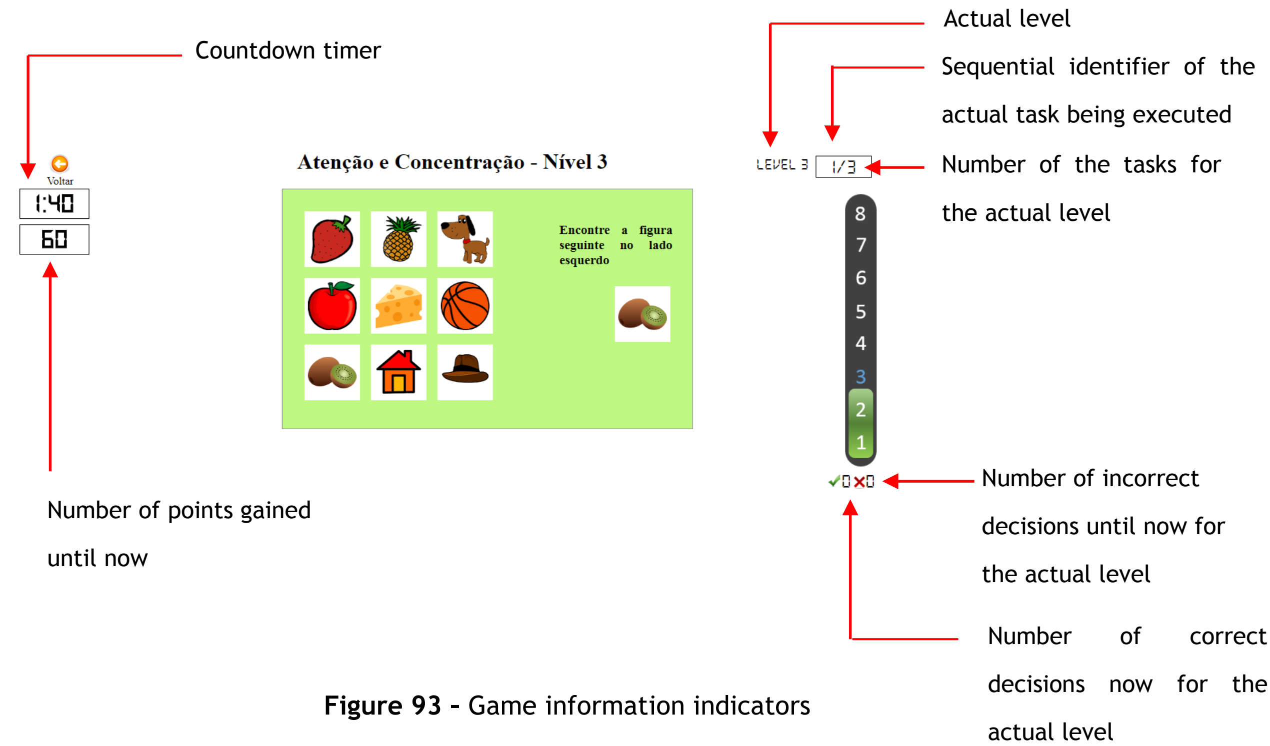


Figure 93 - Game information indicators

When a level is completed, it appears a message indicating that fact accompanied with an illustrative image as presented in Figure 94.

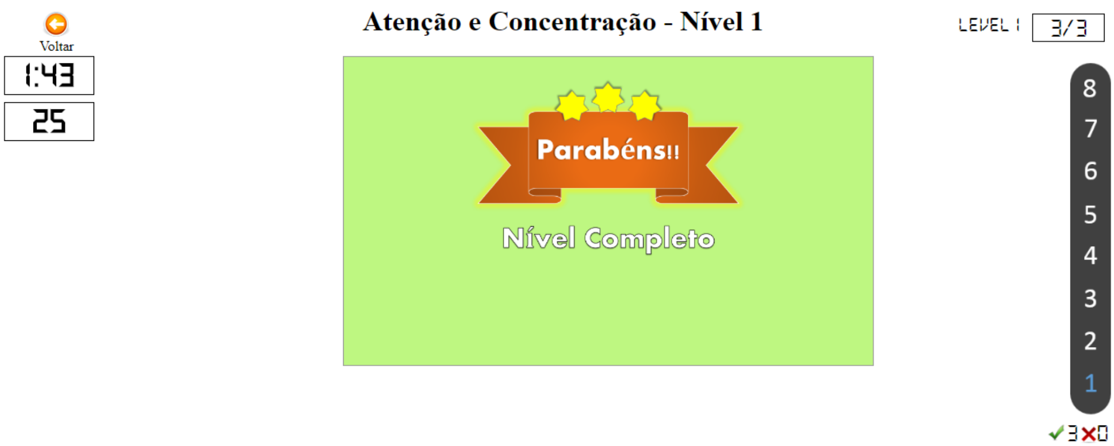


Figure 94 - Feedback indicating that the actual level was completed.

When the game ends because the time limit was reached, it is showed an illustrative image and a message text as presented in Figure 95.

Figure 95 – Feedback indicating that the time limit was reached.

When the user terminates the game before the time limit is reached the feedback is as illustrated in Figure 96.

Figure 96 - Feedback – patient completes all the levels before the time limit is reached.

Levels of difficulty

The levels of difficultly are adapted automatically. Table 17 shows the structure of difficulty used in the games, based on the structure of difficulty used on Attention-concentration game of RehaCom Cognitive Software System. The RehaCom uses 24 levels of difficulty, but we are using only the first 8 levels of difficulty of RehaCom.

RehaCom defines 8 stages with several records of 16 pictures each, starting with low similarity of the objects (defined as easy tasks) up to high resemblance (defined as hard tasks). Each stage consists of 3 levels of difficulty with the matrix containing 3, 6 or 9 pictures. In our version we simplified and we only consider 3 stages with 3 levels of difficulty (the last stage has only 2 levels).

Table 17 - Structure of difficulty (adapted from RehaCom [94]).

Difficulty Level	Difficulty (discriminability of images)	Number of images at matrix
1	1	3
2	1	6
3	1	9
4	2	3
5	2	6
6	2	9
7	3	3
8	3	6

Training Parameters

The manual of RehaCom gives general hints about the training parameters and their effects. We have taken some of these parameters in consideration in the actual implemented version of the game. Despite we have not define yet an interface for configuring these parameters, we consider them as configurable in actual implementation of the game:

- **Level up**: this parameter defines the number of tasks the patient has to solve correctly in succession in order for the level to increase. That is, the next higher level of difficulty is reached when the number of tasks given in Level up parameter is solved correctly. Wrong decisions have to be compensated by the same number of correct choices. In our implementation this parameter is defined for 3.

- **Level down**: the next lower level starts when the number of tasks generated in Level down has been solved incorrectly in succession. In the current version this parameter is not being considered.
- **Limited solution time**: in RehaCom if this parameter is activated If this parameter is activated, the patient's time to solve a task is limited and the limitation depends on the level of difficulty: for the easiest task, in the first level, 1 minute is given. Each level the limitation expands for 5 seconds. With that, an additional time stressor can be set for some patients. If the parameter is switched off, the time to solve a task is unlimited. In our implementation, we defined a time limit for all the game of 2 minutes.

Score

In this version, a scoring system was implemented so that at the end of time one can determine the winner. So, in a task, whenever the user clicks on a correct picture he wins five points and if he clicks a wrong picture he loses the points equivalent to the level.

Multiplayer Competitive version

In the competitive multiplayer version, the screen has two boards, one for each of the players and one reference image for each player, as illustrated in Figure 97. The mechanics of the game for each player is equal to the single player version, except in the termination conditions of the game.

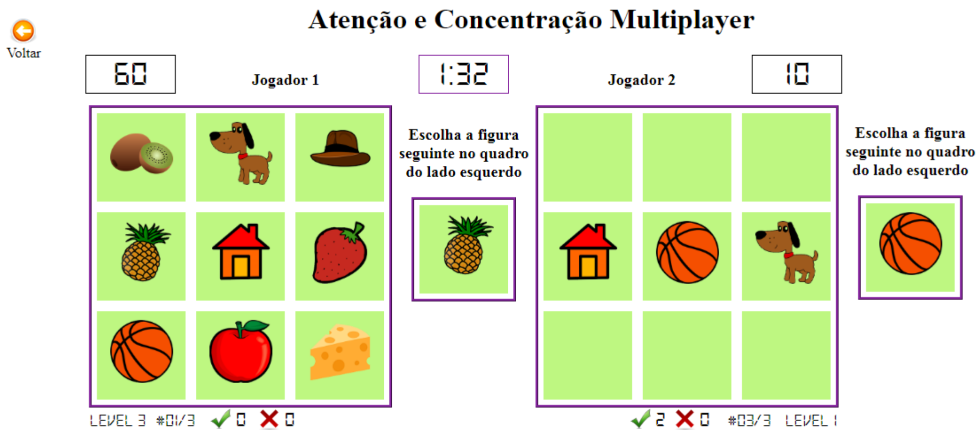


Figure 97 - Interface of the multiplayer competitive version

The game can terminate by time limit, or if one of the players completes all the levels. If the game terminates by time limit, a feedback message is shown indicating that the time limit was reached. The player who has more points wins the game as illustrated in Figure 98. If one of the players completes all the levels, the game terminates, a message is shown to the winner indicating that he completed all the levels and is given to the other player a feedback message indicating that he has loosed.

Figure 98 - Feedback messages when time limit is reached.

Multiplayer Collaborative version

The game starts with an informative screen containing an explanation of the functioning of the game, as is illustrated in Figure 99.

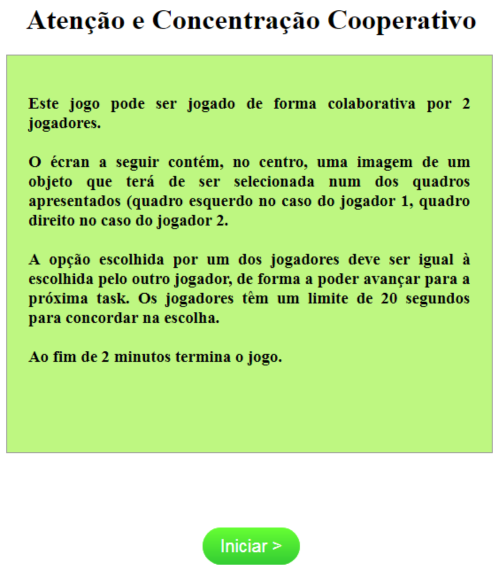


Figure 99 - Attention-concentration collaborative - first screen.

After clicking on the button “Iniciar”, the training screen appears, as showed in Figure 100. The training screen is divided into two parts. The left part presents a board for one of the players and the right part presents a board for the other player. The reference image appears in the middle, between the two boards. On the middle will appear instruction messages as needed. The indicators for the actual level, task level, number of chosen correct words and number of chosen incorrect words are always present and its information is updated when a task is evaluated.

A task is evaluated as soon has both players make the first choice in the respective board.

Figure 100 - Attention-concentration Collaborative – training screen at level 1.

In this version of the game, the patients have to cooperate with each other in order to solve each task which means that they have to agree on the chosen image, even if that is not the correct image. If they choose different images in a task, they have a limit of 20 seconds to agree in the chosen option for that task. This is indicated by a feedback message on the screen informing the patients of the time limit. If after this time limit they don´t choose the same option, a feedback message appears (Figure 101), the task is then evaluated as incorrect and the next task is presented.

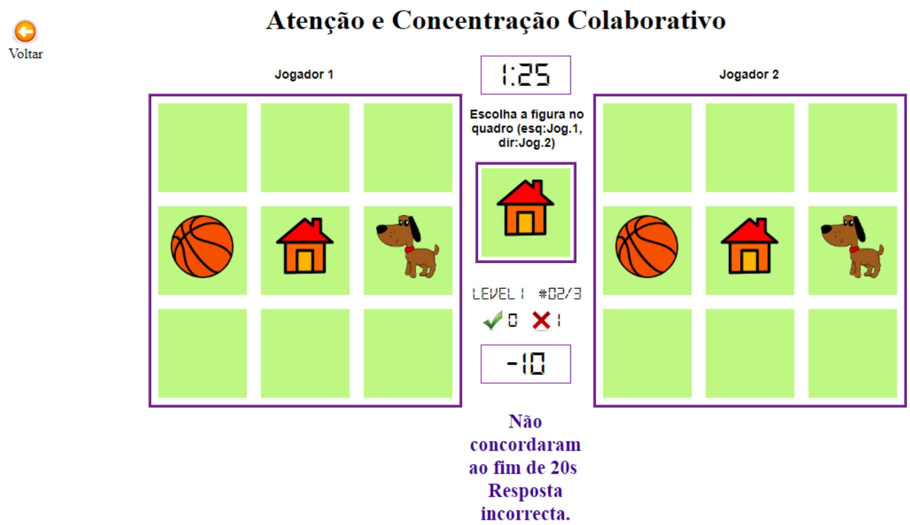


Figure 101 - Attention-Concentration Collaborative - time limit of cooperation feedback.

The conditions for terminating the game can be like in the competitive version by limit time or by both players completing all levels defined for the game.

Collected Data for Progress Monitoring

RehaCom describes the possibilities of analyzing the data in the game in order to find strategies to how to continue the training.

In our current implementation, the game records the following data:

- For each task the data recorded is:
  - Task id (`idTask`)
  - Level id (`dNivel`)
  - Task solved correctly or incorrected (`numEncontradas` and `numIncorretas`)
  - Task score (`scorej1`)
- For each level the data recorded is:
  - Level id (`dNivel`)
  - Seconds registered in Countdown timer (`seconds`)
  - Level score (`scorej1`)
  - Number of tasks solved correctly (`found`)
  - Number of tasks solved incorrected (`incorrects`)
  - Task score (`scorej1`)
- For the game data recorded is:
  - An id for the game (`jogo`): is a string identifying the game
  - Game Levels: the maximum number of levels in the game

- Finished Level: the last level that the patient completed
- Total Time of the game
- Game score (`scorej1`)
- Level Tasks: the number of tasks for the level (assuming that is constant for the game)
- Flag indicating if the user ended the game before time limit
- Flag indicating the reason the game end: 1- User, 2 – time limit
- Total Tasks of the game
- Total of correct decisions in the game
- Total of incorrect decisions in the game

In the multiplayer version, the game records additional data about the second player regarding that it has one more player.

6.3.5.4 Memory for Words (Memory Training)

The aim of this game is to improve memory for verbal material through the exercising of recognition capabilities. In addition, it requires continuous attention from the patient. This game is based on Memory for Words game of RehaCom Cognitive Software System [94]. In the training of verbal memory, the patient has to memorize words (nouns) that are presented on the screen. The words have to be recognized by the patient from a list of irrelevant terms which appear on the screen on time interval limits.

Training Task

In this game, the patient has to memorize a group of words. The game is composed by several levels and each level is composed by several tasks. Every task will consist of an acquisition - and a reproduction phase.

In the acquisition phase, a list of nouns is shown to the patient. This list of words is based on the current level of difficulty. The patient must memorize these words. The period for memorizing is determined by the patient himself. The patient ends the acquisition phase by pressing that button “Continuar”.

Figure 102 presents the interface of the game at level 1 in the acquisition phase. The number of words that appear to memorize depends on the level of difficulty.

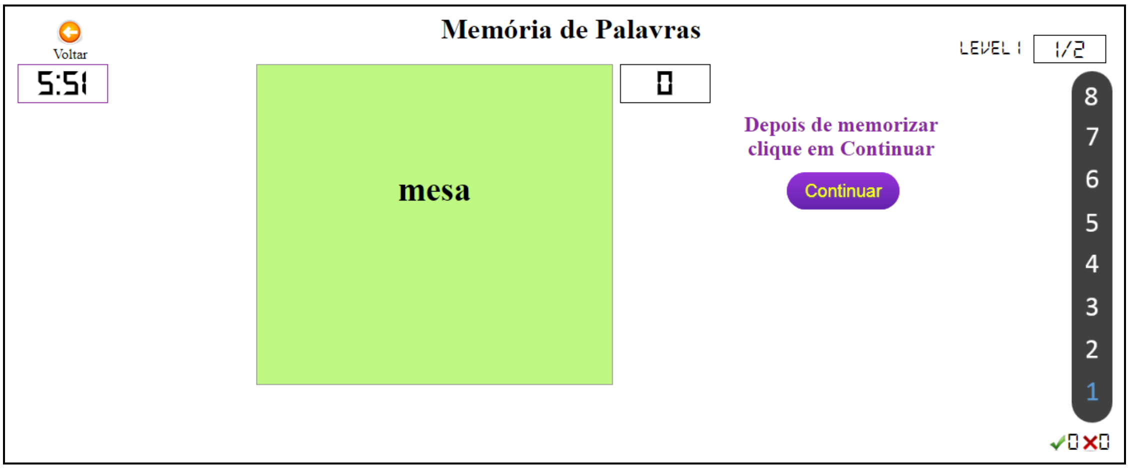


Figure 102 - Memory for Words Game for level 1 – acquisition phase.

Following the acquisition phase is the reproduction phase (Figure 103) when the memorized words have to be recognized and selected from a series of other words. One word appears and stays in screen during a few seconds and then disappears, and after a few seconds, another word appears. The patient can select the correct words clicking with the mouse in a correct word. When he clicks a word, a feedback message appears indicating if it is correct or incorrect. If he misses a word, a feedback message appears indicating that the word was missed.

The reproduction phase ends when all words in a task have been shown. After this the patient performance in the task is evaluated and showed on the screen, informing the patient as to which and how many mistakes were made and whether the patient should continue to the next level of or repeat the same level.

The indicators on the screen showing the total right and total incorrect words for that level are updated with the result of the task evaluation.

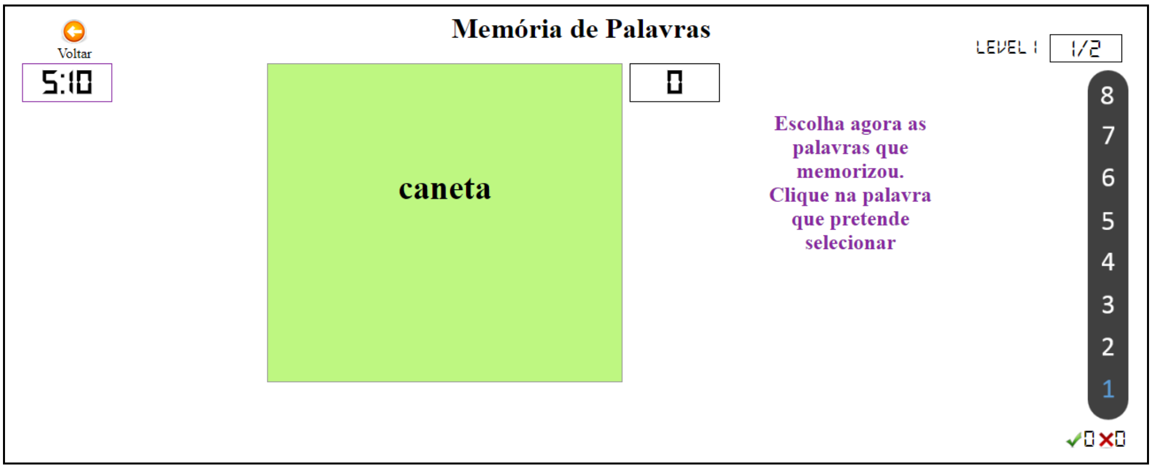


Figure 103 - Memory for Words game -Reproduction phase at level 1.

The actual version of this game is defined for 8 levels and each level has 2 tasks. However, the number of game levels and the task levels can be parametrized. In current implementation, a time limit of 6 minutes is defined to play the game.

Interaction

The game starts with an explanation of what the patient has to do on the next screen, as is illustrated in Figure 104.

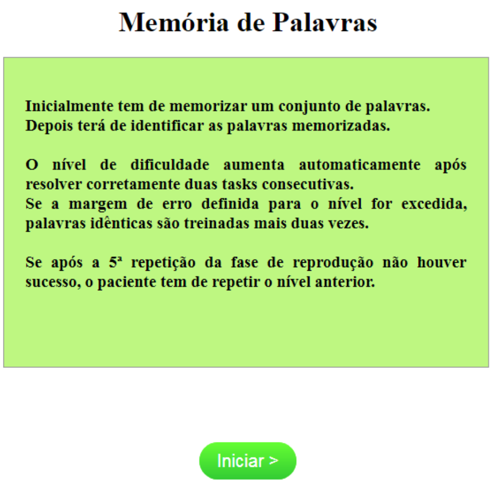


Figure 104 - First screen of Memory for Words game (single player).

After clicking on the button “Iniciar”, the training screen appears. The training screen is divided into two parts. The left part presents a green board in which the words appear one at a time. On the right side will show up instruction messages. The indicators for the actual level, task level, number of chosen correct words and number of chosen incorrect words are always present and its information is updated when a task is evaluated.

The interaction is done via mouse, through a Point-and-Click interface.

The game presents simple plots and two-dimensional images that indicate whether the level has been successfully completed, and the end of playing time.

This game was developed in 2 versions: single player and multiplayer with competitive features.

Performance Feedback

The result of the task in tems of success or insuccess (correct decisions, incorrect decisions or omitted words) is signalized with a message text. Figure 105 illustrates the feedback when the patient selects a correct word in the reproduction phase.

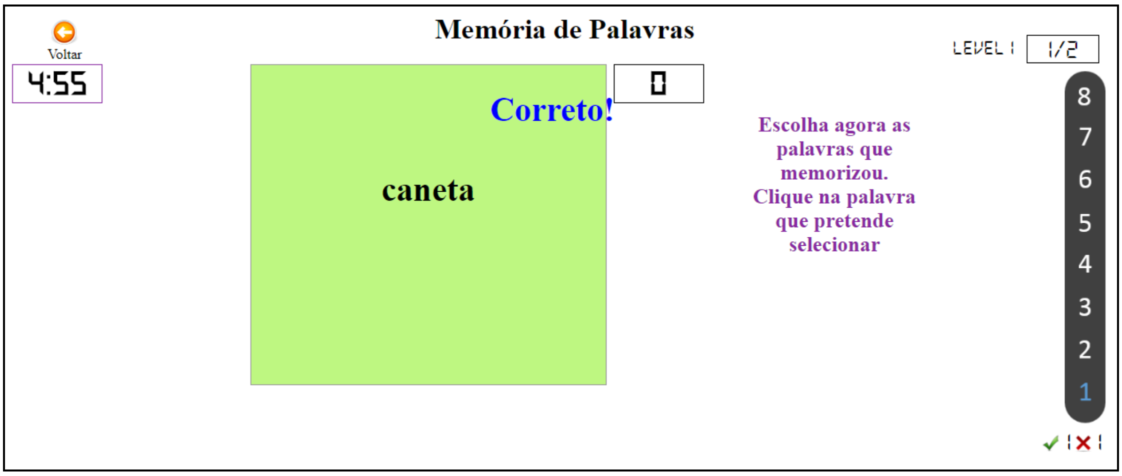


Figure 105 - Memory for words game -feedback message when a word is found.

Figure 106 illustrates the feedback when the patient selects an incorrect word in the reproduction phase.

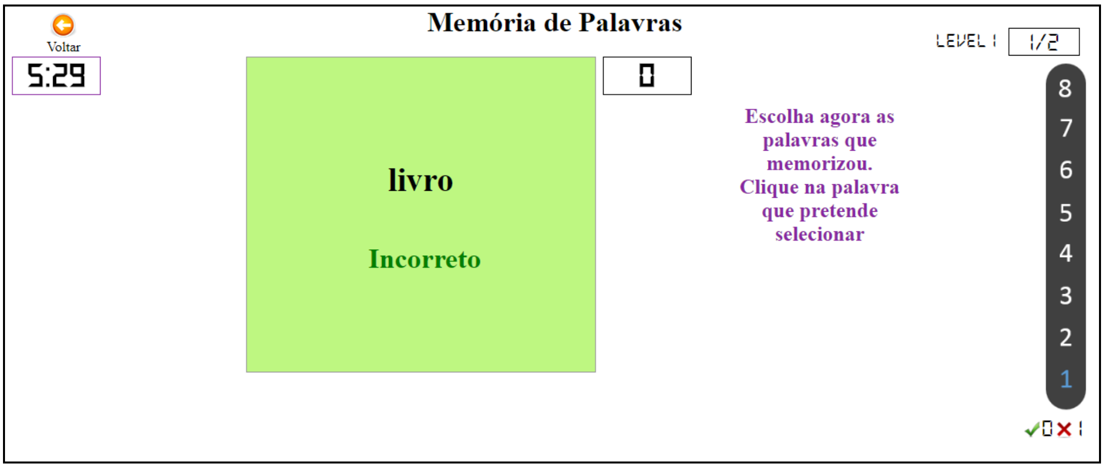


Figure 106 - Memory for Words game -feedback message when a wrong word is selected.

Omitted words are also signalized with a text feedback text message as illustrated in Figure 107.

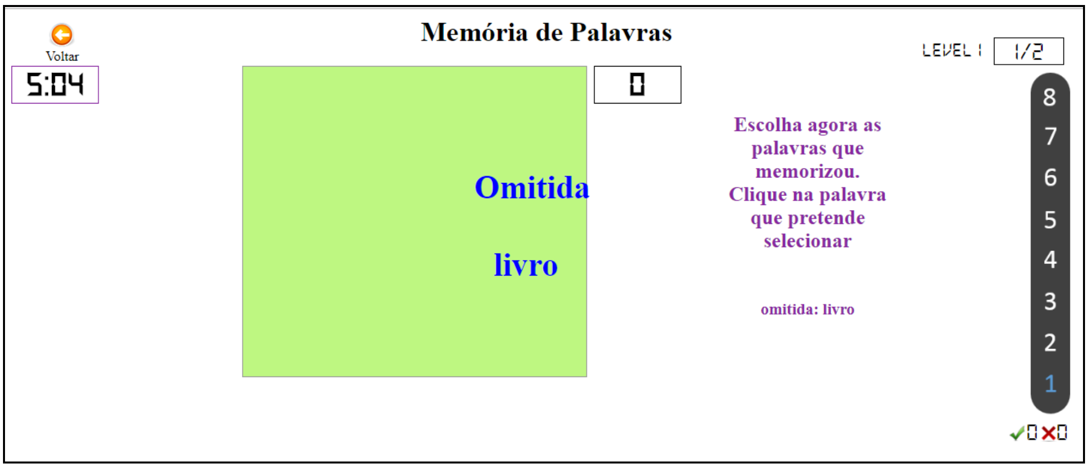


Figure 107 - Memory for words game - feedback message when a word is omitted.

Besides the visual feedback, this game uses a sound feedback that appears in conjunction with the visual feedback message when the patient chooses a correct word and a different sound appears when the feedback message indicating that the word is incorrect is shown.

As in the previous game, each training screen has information about the task (through an identifier) that the patient is resolving, the number of tasks of the level, the information of the actual level, the number of correct decisions in the level and the number of incorrect decisions as illustrated in Figure 93. Any time the user resolves a task in a correct way those information indicators are updated in the screen.This information is therefore always present in the screen.

When a level is completed, it shows a message indicating that fact accompanied with an illustrative image as illustrated in Figure 108.

Figure 108 - Feedback indicating that the actual level was completed.

When the game ends because the time limit was reached, it is showed an illustrative image and a message text indicating that fact, as well as when the user terminates all the levels of the game before the time limit is reached These illustrative images are the same as used in the attention-concentration game and all the previous described game.

Levels of difficulty

The levels of difficultly are adaptive. Table 18 shows the structure of difficulty levels used in the game, based on the Memory for Words game of RehaCom Cognitive Software System. The RehaCom uses 30 stages of difficulty, determined by the kind of the words to be memorized, but we are using only the first eight levels of difficulty of RehaCom and make no distinction on the type of words.

A task is evaluated as "solved" (correctly) if the total of errors is below a defaulted margin of error. The margins of error used in the current implementation are defined in Table 18.

Table 18 - Structure of difficulty (adapted from RehaCom [94]).

Difficulty Level	Number of words	Error margin
1	1	0
2	1	0
3	1	0
4	2	0
5	2	0
6	2	0
7	3	0
8	3	0

As we are using the first 8 levels of RehaCom structure of difficulty and no error is permitted when the task consists of only 4 words, we have only margins of error of 0. In RehaCom, at a level of 5 words, the task is evaluated as "solved" if there is only one mistake and at a level of 9 words two mistakes are allowed.

After receiving an evaluation of "solved" the patient then proceeds to the next level where a new selection of random words have to be memorized.

The words that are used in the current task do not appear in the following task.

The level of difficulty is increased when the patient solves two tasks one after the other.

If the margin of error is exceeded during the reproduction phase of the task, the identical words have to be trained up to two times. The patient has the opportunity to memorize the identical words repeatedly. The order of the words in the acquisition- and in the reproduction phase are variable. In RehaCom, if after the fifth repetition of the reproduction phase, the patient cannot solve the task, then the patient must repeat the previous level. In the current implementation we don´t consider the decreasing of level.

Score

A score can be an element of motivation in the game. In this version, also a scoring system was implemented so that at the end of time one can determine the winner. Therefore, in a task, whenever the user makes a total of errors less or equal the margin of error, he wins five points and if he makes more errors than the defaulted margin of error, he loses the points that are equivalent to the actual level.

Multiplayer Competitive version

In the competitive multiplayer version, the screen has two boards, one for each of the players and one reference image for each player, as illustrated in Figure 109 . The mechanics of the game for each player is equal to the single player version, except in the termination of the game.

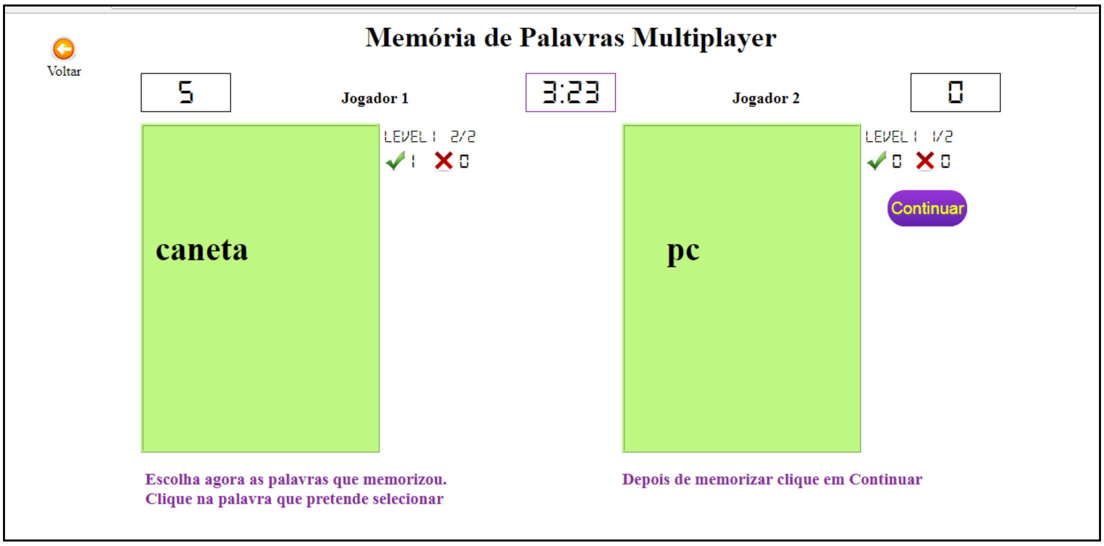


Figure 109 - Interface of the multiplayer competitive version.

The game can terminate by time limit, or if one of the players completes all the levels. If the game terminates by time limit, a feedback message is shown indicating that the time limit was reached. The player who has more points wins the game as illustrated in Figure 110. If one of the players completes all the levels, the game terminates, a message is shown to the winner indicating that he completed all the levels and is given to the other player a feedback message indicating that he has loosed.

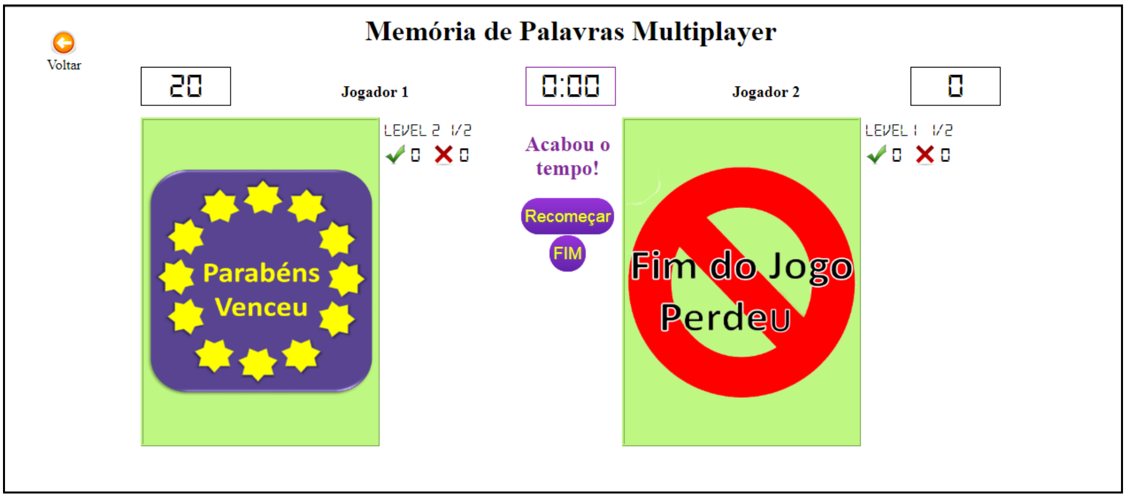


Figure 110 - Feedback messages when limit time is reached.

Collected Data for Progress Monitoring

RehaCom describes the possibilities of analyzing the data in order to find strategies to how to continue the training.

In our current implementation, the game records the following data:

- For each task the recorded data are:
  - Task id (`idTask`)
  - Level id (`dNivel`)

- Flag indicating if the task corresponds to a repetition task (`taskRepeat`)
- Flag indicating the sequence number in the phase of repetition (`repeatsequence`)
- Number of correct words found (`found`)
- Number of incorrect words selected (`incorrects`)
- Number of words omitted (`omitted`)
- Total of errors (`errorsTotal`)
- Task score (`scorej1`)

- For each level the recorded data are:
  - Level id (`dNivel`)
  - Seconds registered in Countdown timer (`secondsCountdown`)
  - Number of to find in each level (`numCorrectWords`)
  - Level score (`scorej1`)
  - Number of words found in the level(`certas`)
  - Number of words incorrectly found in the level(`erradas`)
  - Number of omitted words in the level (`omitidas`)
  - Number of errors of the level (`erros`)
  - Task score (`scorej1`)

- For the game the data that is recorded are:
  - An id for the game (jogo): is a string identifying the game
  - Game Levels: the maximum number of levels in the game
  - Finished Level: the last level that the patient completed (`finishedLevel`)
  - Total Time of the game (`secondCountdown`)
  - Game score (scorej1)
  - Level Tasks: the number of tasks for the level (assuming that is constant for the game)(`levelTasks`)
  - Number of times to repeat when there is a error in a task (`timesToRepeat`)
  - Flag indicating if the user ended the game before time limit
  - Flag indicating the reason the game end: 1- User, 2 - time limit
  - Total Tasks of the game (`totalTasks`)
  - Total of correct decisions in the game (`totalCertas`)
  - Total of incorrect decisions in the game (`totalErradas`)
  - Total de palavras omitidas no jogo (`totalOmitidas`)
  - Total de erros no jogo (`totalErros`)

In the multiplayer version, the game records additional data regarding that it has one more player.

6.4 Summary

In this chapter, we presented the main details concerning the implementations done in order to study the introduction of a set of features in games for cognitive rehabilitation that will contribute to make the games more motivating and to increase the motivation of patients in rehabilitation.

We presented first the preliminary work done with a prototype for motion detection and then the Rehab+ platform that is composed of a set of 12 web-based games. We described in detail the main games of Rehab+ and its variations in terms of competitive and collaborative features. We also described each of the implemented games in terms of the features we proposed to integrate and that we described in chapter 5.

Chapter 7

Experiments and Results

7.1 Introduction

This chapter presents a description of the experiments performed to validate the proposed framework and their results. Three experiments were conducted and are described in this chapter. The first experiment consisted in the testing of a serious game prototype that was developed as a preliminary usability study in order to evaluate the effect of the introduction of new forms of interaction in rehabilitation serious games. The participants were healthy users and their opinions were obtained through a questionnaire. The second experiment aimed at testing the usability of Rehab+ platform and the games that are included in it and the participants involved were healthy users. The third experiment refers to an usability study of Rehab+ games involving elderly users.

7.2 Preliminary Study: Motion Detection Prototype

To validate the prototype described in section 6.2, we conduct a small usability study with 20 healthy users (12 female and 8 male, with age between 11 and 50 years old) in order to evaluate the playability of the game in what concerns three input forms of interaction.

The methodology applied was the gathering of opinions using a questionnaire that includes questions regarding individual assessments of usability.

7.2.1 Experiment

First, we made a small demonstration of the three input options of the game. Each user then played five times the game in each of its three input options and filled a usability questionnaire, with 5 points likert-scale. The first two times were for him to become accustomed to the interface and the remaining to evaluate the game.

Figure 111 presents an excerpt of the questionnaire used.

1) **Evaluate the "Memory for Words" game in each input form in respect to the following (choose only one option):**

1. Strongly disagree **2.** Disagree **3.** Neither agree nor disagree 4. Agree **5.** Strongly agree.

	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5						
1. The game is enjoyable.						**2.The game is easy to play.**						**3. The game is challenging.**						**4. I would play it again more times.**					
Mouse Detection	☐	☐	☐	☐	☐	Mouse Detection	☐	☐	☐	☐	☐	Mouse Detection	☐	☐	☐	☐	☐	Mouse Detection	☐	☐	☐	☐	☐
Sound Detection	☐	☐	☐	☐	☐	Sound Detection	☐	☐	☐	☐	☐	Sound Detection	☐	☐	☐	☐	☐	Sound Detection	☐	☐	☐	☐	☐
Motion Detection	☐	☐	☐	☐	☐	Motion Detection	☐	☐	☐	☐	☐	Motion Detection	☐	☐	☐	☐	☐	Motion Detection	☐	☐	☐	☐	☐
5. The feedback is effective.						**6. The input mechanism is intuitive.**						**7. The game interface is consistent.**						**8. The game interface is clear.**					
Mouse Detection	☐	☐	☐	☐	☐	Mouse Detection	☐	☐	☐	☐	☐	Mouse Detection	☐	☐	☐	☐	☐	Mouse Detection	☐	☐	☐	☐	☐
Sound Detection	☐	☐	☐	☐	☐	Sound Detection	☐	☐	☐	☐	☐	Sound Detection	☐	☐	☐	☐	☐	Sound Detection	☐	☐	☐	☐	☐
Motion Detection	☐	☐	☐	☐	☐	Motion Detection	☐	☐	☐	☐	☐	Motion Detection	☐	☐	☐	☐	☐	Motion Detection	☐	☐	☐	☐	☐
9. The game colours are appropriate.						**10. The speed of the game is too fast.**																	
Mouse Detection	☐	☐	☐	☐	☐	Mouse Detection	☐	☐	☐	☐	☐												
Sound Detection	☐	☐	☐	☐	☐	Sound Detection	☐	☐	☐	☐	☐												
Motion Detection	☐	☐	☐	☐	☐	Motion Detection	☐	☐	☐	☐	☐												

Figure 111 - An excerpt of the questionnaire used in the playability study.

7.2.2 *Results*

Most of the participants enjoyed playing all the input options, with the sound input option being the most enjoyable and the motion option being considered the least enjoyable.

The sound input option was considered the easier to play and the mouse input option the less easy to play. Despite this, the mouse input option was considered the most intuitive and the motion input option the less intuitive. Still, about 40% of the participant's didn´t find the game challenging, although about 30-35% found the contrary.

The majority of players considered play more times the game, with the sound input option being the most chosen and the mouse input option being the less chosen to play again. In what concerns feedback, the sound option was found the most effective and the mouse option the less effective.

Most of the participants found the game interface consistent and clear. In respect to game colors, about 35% of participants found it appropriate (15% disagreeing). In what concerns the speed, the majority of the participants considered it appropriate.

When asked to compare the three input game options, the participants felt more involved with the motion input option, considered the mouse option the most intuitive input and would play again the motion and mouse option.

Figure 112 presents a chart illustrating the results obtained in each input option in respect to question 1 of the questionnaire.

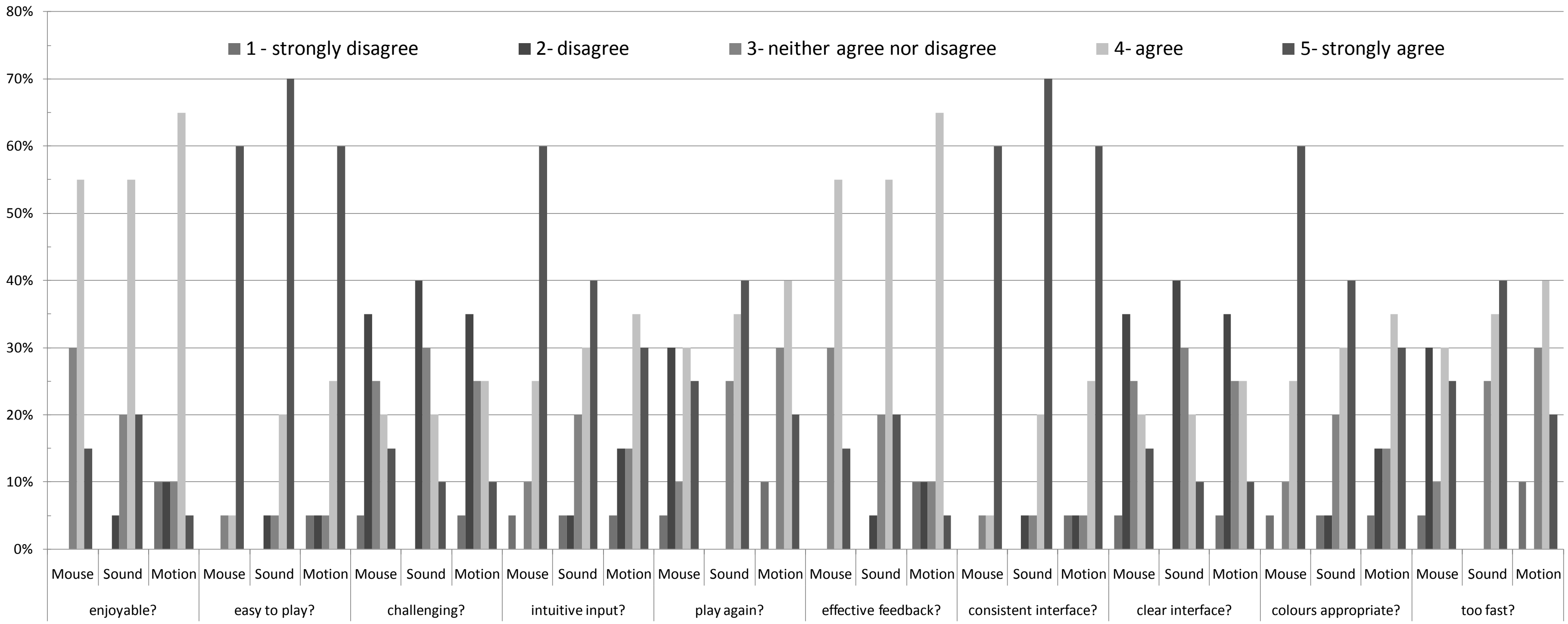


Figure 112 - Results from the questionnaire relatively to question 1.

7.2.3 Comparison with Reviewed Systems

In this section, we present a comparison of the characteristics of our prototyped system with the systems that were described and reviewed in Section 2.3.2 (“Review on Serious Games for Rehabilitation”), and summarized in Table 3, according to the criteria we have chosen to classify the referred reviewed systems (described in Section 4.2.1).

Our system uses three input devices as interaction technology: a webcam, a microphone and a keyboard. These input devices can be used alternately in the game. In the beginning of the game, the player can choose among three input options: mouse, motion and sound. The player can use only the mouse as input device in the first option of the game; in the second option of the game, he must use movements of his body (hands, head, arms) to make the selections and play the game; in the sound option, the player has to make some sound effect (talk, clapping, yell, etc.) to play the game.

Our system does not provide a facility for collaboration/competition. This facility would be considered in future versions of our game.

In respect to application area, the prototyped game is to be used in a cognitive rehabilitation context. The game implemented is a re-implementation of the game mechanism of a words memory game included in a widely used and tested rehabilitation system that is described in section 2.3.2.4 –the RehaCom system, which use is well proven in cognitive rehabilitation sessions.

For each of the input options of the game, we have considered in its design some of the design principles that should exist in a rehabilitation context such as performance feedback, adaptability, progress monitoring and portability. Performance feedback is created in the game through the feedback given to the player by visual messages for right or wrong answers, information about score, sprites changing text messages and text colors. Adaptability is provided by changing the speed and difficulty of the game, according to player’s performance. Beyond the game mechanics, progress monitoring is also a fundamental feature in order to enable track and analysis of the rehabilitation plan. This facility was not used in this study. In terms of portability, our system can be used for home rehabilitation, as it only requires a laptop/ desktop computer with internet access, a webcam and a microphone. The problems found as a result of the playability study were useful to improve the next versions of the games.

Compared with the reviewed systems, our system gathers a set of advantages that can be enunciated as low cost, portability, easy access, and a large diversity of interaction mechanisms, attracting a larger number of players and a larger number of player interactions with the game. Another major advantage is that it is based in a game well tested in clinic terms and that makes part of a reference system used in cognitive rehabilitation. Our game uses the game mechanism of this widely tested rehabilitation game and augments it with new interaction mechanisms. Most of the systems reviewed are based in games which do not have rehabilitation requisites in mind in its design.

7.2.4 Conclusions

To study the effect of the introduction of new forms of interaction in rehabilitation serious games a serious game prototype was developed and tested with healthy users that can be played in three different versions which differ in the interaction input form: mouse, sound or motion.

Some design problems were identified in the study but this identification was useful to improve future versions of the game, such as the use of more appropriate colors in the screens and the introduction of more instructive text messages and sounds. Also in the sound and motion option of the game, would be desirable the introduction of a more reliable facility to make a proper calibration of the input sensors and recognition procedures, increasing the overall robustness of the system, in varying noise and illumination conditions, and also adapted to the patient intrinsic motion and voice characteristics, for instance. Some participants in the evaluation reported they did not like much the motion input option, or considered it less intuitive, simply because they didn´t know how much they have to move in front of the camera to make the words selections. In many situations, a similar problem occurred for the sound option. However, despite of that, the sound and motion input option of the game provided the most involvement of the users in the game and were the options the users showed more interest to play again.

The prototyped game can be played online, making it more accessible to all users, including to patients in rehabilitation, and providing a low cost solution to patients training and enabling a home rehabilitation, in addition to traditional therapy. The input mechanism is more intuitive and can more easily be adopted by people with disabilities and impairments in rehabilitation. This option to develop online games that may used by a large set of users was used in the next steps of the work.

This preliminary work also showed the need to introduce a facility of saving user profiles (for progress monitoring) and to apply these new forms of input to other games similar to the ones in RehaCom and also this was continued in the next work steps in order to enable a more comprehensive study involving a larger sample of user. In overall, the conducted user study demonstrated that new forms of interaction were interesting to the users, despite some difficulties, and made the user experience more attractive and intuitive.

7.3 Rehab+ – Usability Study with Healthy Users

The tests described here were designed primarily to evaluate the usability and attractiveness of the games of Rehab+ Platform, to see if they are easy to play and interact, if it is easy to understand what is asked in each of them, if users like the games and if these are appealing.

The tests included subjects willing to participate in the experiment (volunteers) and followed two different modalities: tests in the classroom and online tests. In the latter, only the single player versions of the games were tested. The tests in the classroom took place in LAP4, a computer laboratory at the Information Systems Department in the University of Minho. This experiment included mostly the participation of University of Minho students' volunteers.

The user tests counted on a total sample of 58 subjects, 36 took part in the online test and 22 participated in tests in the classroom. An initial pre-test was done in classroom, with nine subjects in order to finalize the details of the tests and games. After this pre-test, some errors detected in the games were corrected. Another objective was to verify if there were different opinions about the usability and attractiveness in the groups that played online or in the classroom.

7.3.1 Experiment

The tests were performed according to two different approaches: in classroom and online. The online tests included only games in single player version, since it is impossible to control whether users actually played the games with other users or not, and also because for these games it is required the installation of a specific software for allowing the use of simultaneously two independent mice in the same computer. In this approach, each of the games has a small description that clarifies about the goal and the rules of the game and how to play it.

In the tests conducted in the classroom, subjects started to play alone all single player games, and then were grouped in pairs to test the multiplayer games. The tests began with a short explanation of the research and about the purpose of these games. Then each subject read and signed an informed consent, which contained all the information regarding the research and testing in which they would participate.

In what concerns the arithmetic game it was not defined any specific order for testing the two modes of interaction, which resulted in some participants experiencing first the interaction via mouse and others via voice commands.

In relation to the multiplayer version of the sorting game, all subjects experienced first the normal version and then the version with handicapping. It was not explained to the subjects nothing about the handicapping system before they played the games. In the questionnaire, all subjects were asked about the handicapping system, and if they noticed its existence during the game and all answered, they did not notice.

It was shown for each subject how to interact with each game, and each one played the games during about 15-20 minutes before completing this questionnaire.

7.3.2 Instruments used

It was developed a questionnaire (Annex B) that was applied to all subjects that participated in the test. In this questionnaire, questions regarding multiplayer experiences were removed for the online participants.

The questionnaire has an initial section, which aims to make a characterization of the sample (age, gender, and education, among others). In addition, it uses two validated instruments, commonly used in testing computer games: CEGEQ (Core Elements of the Gaming Experience Questionnaire), IMI (Intrinsic Motivation Inventory) and SUS (System Usability Scale). In the end, the questionnaire includes some questions that specifically address a comparison between the games modes and forms of interaction and an open response space to collect any comments that users want to express.

IMI is a multidimensional assessment tool that evaluates the subjective experiences of the participants in relation to the activity they experienced which, in this case, is in relation to all the gaming experience of activity and interaction with the Rehab+ platform. We adapted this instrument in order to use only one of their ranges, specifically the scale that measures the interest / satisfaction of the subjects in relation to the whole experience. The analyzed questions were: “1. I enjoyed doing this activity very much”; “2. This activity was fun to do”; “3. I thought this was a boring activity”; “4. This activity did not hold my attention at all”; “5. I would describe this activity as very interesting”; “6. I thought this activity was quite enjoyable”; “7. While I was doing this activity, I was thinking about how much I enjoyed it”.

The SUS is an instrument composed of 10 questions used to assess the usability of various products and services, hardware, software, among others. The questions in this instrument have been adapted to refer to the whole experience of interaction with the Rehab+ platform and the games that are part of it. The SUS items are: “1. I think that I would like to use this system frequently”; “2. I found the system unnecessarily complex”; “3. I thought the system was easy to use”; “4. I think that I would need the support of a technical person to be able to use this system”; “5. I found the various functions in this system were well integrated”; “6. I thought there was too much inconsistency in this system”; “7. I would imagine that most people would learn to use this system very quickly”; “8. I found the system very cumbersome to use”; “9. I felt very confident using the system”; “10. I needed to learn a lot of things before I could get going with this system”.

The CEGEQ was developed to measure the observable variables (items) in order to understand the user experience by playing the game. This section consists of 34 items (questions) that make up 10 dimensions that can be grouped into five main dimensions. For each item you can assign a scale (Likert) of 7 values ranging from "strongly disagree" and "strongly agree". The dimensions are: Enjoyment, Frustration, CEGE, Puppetry, Video Game, Control, Facilitators, Ownership, game-play and Environment [347].

The 5 main dimensions of the CEGEQ are:

- Enjoyment - related to the pleasure of the user during the experiment. The questions assigned to these dimensions are: 1; 4 and 5.
- Frustration - measures the levels of user frustration during and after the experiments. The questions assigned to these dimensions are: 2 and 3.
- CEGE - allows evaluating key elements of the game experience. This is a general dimension of the questionnaire related to the interaction between the game and the user. The questions allocated to these dimensions are: from item 6 to the item 34.
- Puppetry - brings together the dimensions Control, Facilitators and Ownership. This dimension is affected by three conditions the control, facilitators and domain. This dimension is responsible for determining the users' interaction levels with the game through the control the user has on the game. The control produces domain, which in turn produces pleasure for the game. This domain is produced by facilitators who offset the sense of control. The questions allocated to these dimensions are: Control: 6-12, 34; Facilitators: 13-18; Ownership: 19-24; Control / Ownership: 25.
- Video-game - consists of the Environment and Game-play dimensions. The video-game user perception is formed by the environment and the game played, i.e. is the analysis of the graphical environment of the scenarios and the perception of the user about the games. The questions allocated to these dimensions are: Environment: 26;27; Game-play: 28-33.

These dimensions assess specific aspects of the game such as graphics and controls as well as user experience concepts such as satisfaction, frustration or the level of control that users feel in relation to the game. In the present investigation, the four items related to sound were removed, since none of the games contained an auditory component, a situation predicted by the authors of the instrument [347]. The subjects responded to this instrument in relation to each of the experienced games.

7.3.3 Results

In this section, the results of the questionnaires answered by the subjects involved in the tests of the Rehab + platform are analyzed. The questionnaires were analyzed using the IBM SPSS Statistics software, in which were inserted all the answers and the statistical analysis was performed. It was considered 0.05 for the significance level. Statistical measures such as mean and standard deviation were applied to characterize the sample; and Mann-Whitney test was used to verify differences between two independent samples, namely the difference between the classroom and online tests and to verify the differences between the considered groups of age (<30 years, >30 years).

7.3.3.1 Sample Characterization

Table 19 shows a summary characterization of the sample that participated in the tests on the Rehab + platform.

Table 19 - Characterization of the sample

	Sample (N = 58)			
	n	%	*M*	*SD*
Gender				
Female	17	29.3		
Male	41	70.7		
Age			25.4	7.8
Categorized Age				
< 30	49	84.5		
> =30	9	15.5		
Education Level				
Higher Education	50	86.2		
Non-higher Education	8	13.8		
Motor Problems				
Yes	1	1.7		
No	57	98.3		
Handedness				
Right Handed	51	87.9		
Left-handed	7	12.1		
Color Blindness				
Yes	0	0		
No	58	100		
Do you regularly use the computer?				
Never	0	0		
Rarely (once a month)	0	0		
Sometimes (one time per week)	1	1.7		
Very often (every day, 1 hour or less)	5	8.6		
Always (every day, over 1 hour)	52	89.7		
Do you regularly play computer games?				
Yes	21	36.2		
No	37	63.8		

Table 20 presents the characteristics of the samples (of the classroom and online tests) and mean and standard deviation of the respective age.

Table 20 - Samples characterization of classroom and online tests

Classroom test				Online test			
Gender (Females; Males)	Age (mean; std)	Motor difficulty (yes; no)	Education Level (High School/BSc/MSc/PhD)	Gender (Females/Male)	Age (mean/std)	Motor difficulty (yes/no)	Education Level (High School/BSc/MSc/PhD)
6; 16	27; 9.2	1; 21	4; 8; 10; 0	11; 25	25; 6.9	0; 36	4; 18; 12; 2

A total of 58 people participated in these tests (22 in the tests in the classroom and 36 in online tests), of which 17 were female and 41 were male. Participants have a mean age of 25.4 years and the total sample varies between 19 and 48.

Regarding education, 86.2% of the sample concluded or is attending higher education. The majority of the sample is composed by right-handed (87.9%) and only 7 subjects claim to be left-handed.

Only one participant reports having motor difficulties, but does not specify which ones. None of the participants suffers from color blindness.

Most participants have computer use experience, 89.7% say they use the computer daily for more than an hour. No participant states have never used a computer.

Regarding the experience of using computer games, 5 participants report never having played computer games, 16 play once a month and 16 once a week, the remaining play every day. These data were analyzed and it was decided to classify the participants as frequent users or not of computer games. To do so, it was agreed that the responses: "Frequently (every day, 1 hour or less)" and "Always (every day, more than 1 hour)" would be considered as "frequent use", and all the others responses as "non-frequent use". Therefore, it is considered that 63.8% of participants do not use computer games frequently.

7.3.3.2 Results of the CEGEC questionnaire

CEGEQ allowed understand the user experience by playing each game. Table 21 shows the mean (M) and standard deviation (SD) in all CEGEQ dimensions related to all the played games.

Enjoyment dimension determines whether the user has a positive experience with the game. For this, it turns out that the Sorting multiplayer game has the highest value (94.6%) while the Arithmetic game in voice interaction mode has the lowest value (73.3%). In general, the highest values of this dimension are observed for the games with multiplayer version, all above 90%. A direct comparison between the types of mouse interaction (86.4%) and voice (73.3%) Arithmetic game show that users rate the experience using the mouse as more positive. If the comparison is made in the same game but this time on the playing side, the multiplayer experience (91.6%), was considered more positive than the single player version (86.4%). The same analysis can be achieved with respect to the Sorting game, again with the multiplayer version presenting a higher result (94.6%) compared to the single player (86.9%).

Table 21 - CEGEQ results by game.

	Memory		Sorting		Arithmetic		Arithmetic - Voice		Tic-Tac-Toe		Arithmetic MultiPlay		Sorting MultiPlay		Sorting Handicapp	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Enjoyment	88	15.4	86.9	15.7	86.4	18.4	73.3	25.5	86.8	16.6	**91.6**	10.1	**94.6**	7.8	**92.9**	9.6
Frustation	22.9	17	24.1	16.3	20.9	12.8	**39.7**	27.6	28.6	20	21.4	11	21.1	10	21.8	10.5
CEGE	78	8.3	77.9	8.4	77.7	9.5	72.5	11.6	80.6	6.7	80.8	6.9	**81.6**	5.8	81.1	5.7
Control	91.1	8.9	89.4	10.4	**88.7**	15.3	**77.9**	19.3	91.9	10.3	90.7	9.8	92.3	8.6	91.5	9.6
Faciliatators	66.5	10.8	67.5	10.1	67.3	10	66.5	10.7	72.9	7.5	71.4	9.1	72.6	7.5	72.5	7.5
Ownership	70.9	13.1	70.1	12.8	70.5	13.5	**65.2**	13.6	73.4	11.6	72.3	12	73.2	11.6	73.2	11.6
Control/Ownership	54.9	35.4	55.2	35.1	54.9	35.4	53.9	33.9	55.8	35.5	54.5	33.2	55.8	34.4	55.8	34.4
Environment	85.3	18.9	88.3	14.9	87.8	16.9	86.2	18.1	93.8	10.2	94.2	10.5	**94.5**	9.8	**94.5**	9.8
Game-play	80.1	10.7	80.6	10.3	81.2	9.6	77	12.2	80.2	7.6	85.3	6.4	84.6	5.8	83.4	4.7
Puppetry	70.9	11.3	70.5	11.1	**70.4**	11.9	**65.9**	12.9	73.5	9.9	72.3	9.4	73.4	9.3	73.2	9.4
Video-game	82.7	13.3	84.5	11.3	84.5	11.7	81.6	13.8	87	8	89.7	7.1	89.6	6.8	89	6.6

The results of Frustration, which measures the frustration of users in relation to those skilled games, are relatively low, on average 25.06%. The highest value is observed in Arithmetic game with voice interaction (39.7%). The lowest value (20.9%) is recorded for Arithmetic game by mouse interaction mode.

The Control scale assesses the user's ability to make the game correspond to their actions. Note that this value is quite different compared to the mode of interaction with the Arithmetic game, 88.7% for the mouse, 77.9% for voice, claiming that users feel more difficult to control the game using the voice.

The way the game is presented, its design, its graphics and its scenarios are evaluated aspects in scale Environment, which has high results, all above 80%, which shows the satisfaction of users with the visual aspect of all games. The Memory game has the lowest value (85.3%), while the Sorting game registers the highest value, 94.5% in their multilayer version and 88.3% in the single player mode.

The Game-play dimension evaluates the perception of users in relation to the goal of the game, in relation to what the game does and its rules. The lowest value in this range is recorded for Arithmetic game with voice interaction (77%). This can be explained partly by the fact that some tests have occurred in the online mode, having no contact with the users, except for the initial appeal of participation, spread via email and social networks. Although this alert notified that this type of interaction only works in Google Chrome browser, the rules of the game being exposed before the start of the game and verbal commands being always visible in the game window, there were several comments referring the inability to interact with the game, so it appears that the use of this form of interaction requires a special care and initial explanation.

The highest score in relation to the gaming experience was in the Sorting game in the multiplayer option, with a score of 81.6% in CEGE dimension.

In general, all games had good results regarding the questionnaire CEGEQ. The Sorting game in multiplayer aspect, meets users' preferences in the opposite direction is the Arithmetic game in with voice interaction.

7.3.3.3 Analysis of differences between groups

The sample was divided into two subgroups taking into account some criteria (gender, age, schooling, computer playing and test modality) in order to see if there are significant differences between them. Thus, differences were tested in relation to the gender of the participants (male or female), their age (more and less than 30 years), schooling (higher education and non-higher education), the frequency with which they play computers (every day or not) and to the modality of the test (presence and online).

The exploratory analysis of the data revealed that there is no normality in the data distribution; therefore, the criteria for the use of parametric tests are not met. Thus for this analysis of differences was used non-parametric statistics, more specifically the Mann-Whitney test.

There were significant differences ($P = 0.002 < 0.05$) in relation to the Enjoyment scale with respect to the modality of the test (online and in classroom).The mean values for this scale are significantly higher in classroom tests (38.00 vs 24.31). Among the results of the Control scale there were also significant differences ($P = 0.002 < 0.05$) in relation to the modality of the test (online and classroom tests), values for this scale were significantly higher in classroom tests (38.30 vs 24.13). It is possible that the online test mode has impaired the voice interaction mode. Firstly, because there was no initial follow-up, explaining to the subjects how to interact with the game. However, a message containing a set of information about this was made available at the beginning of the game; and then by the obligation to perform these tests in the Google Chrome browser, which was also disseminated and recalled when the call for participation in these tests was disseminated. It should be noted, however, that despite this, several users reported as a final comment to the games a large difficulty of interacting in the voice-controlled version.

In relation to the modality of the test (online and classroom), there were still significant differences (P = 0.015 <0.05) with respect to the IMI questionnaire. This questionnaire evaluates the intrinsic motivation in relation to the activity tested, in this case, the questions related to the entire experience of using the Rehab + platform. The values of this scale are significantly higher in classroom tests (36.32 vs 25.33).

The SUS questionnaire was used to evaluate the usability of the entire platform. There were significant differences (P = 0.046 <0.05) in relation to the age (<30 years;> 30 years) of the users, and the values of this questionnaire were significantly higher in participants older than 30 years (39.78 vs 27.61).

7.3.3.4 Differences between the modalities of interaction

The tests of differences concretized so far aimed to understand if there were significant differences in relation to two distinct groups (independent samples), for the same variable. The differences tests for paired samples aim to identify significant differences in relation to the same sample and to different variables. In this sense, these tests were used to analyze the differences in relation to the Enjoyment and Control scales, for the Arithmetic game in both its interaction modalities (mouse and voice).

As the sample size is greater than 30 (N = 58), the t-test was used for paired samples. There was a significant difference between the values of the Enjoyment scale (P <0.001 <0.05), with the results of interaction with the mouse (M = 86.37, SD = 18.4) higher than those with voice interaction (M = 73.32, SD = 25.51). It is concluded that the participants felt that the interaction experience with the Arithmetic game using the mouse was more positive than the interaction by voice.

The same analysis taking into account only the participants in the online tests also reveals significant differences (P <0.001 <0.05), again being the interaction results with the mouse (M = 83.6, SD = 20.56) higher than the voice interaction = 65.74, DV = 26.35). To carry out this analysis, but only taking into account the participants in the classroom tests, the Wilcoxon test was used, since the sample is less than 30 (N = 22) and the exploratory analysis of the data reveals that the Principle of normality. This test indicates that there are no significant differences (P = 0.075> 0.05). The tests carried out reveal that the users who participated in the classroom tests do not present significant differences in the way they evaluate their experience with the modalities of mouse and voice interaction in relation to the Arithmetic game. Unlike what happens in online games, where these differences exist and are significant. This reinforces the theory that the lack of follow-up and explanation of the way this modality works may have influenced the users' experience. Without these initial explanations, the subjects found it more difficult to use different interaction techniques than usual. Nor could it be ruled out that some of these users did not have microphones available which could, or even did, use microphones that were of poor quality and did not allow effective interaction. It is also impossible to guarantee that the tests were performed in an environment with little background noise, which also impairs this mode of interaction. It is advisable that in future tests / uses an effort is made to ensure that users are correctly informed of the best use of this technology and of the technological / environmental assumptions required for its use.

The same comparison was made but in relation to the Control scale. There were statistically significant differences in the values of this scale, in relation to the two modes of interaction of the Arithmetic game. These differences were verified for the whole sample ($P < 0.001 < 0.05$), online tests ($P < 0.001 < 0.05$) and classroom tests ($P = 0.001 < 0.05$). In all cases, the results of the interaction with the mouse were superior to those of the interaction with the voice. These results reveal that the subjects felt more in control of the game with the use of the mouse.

7.3.3.5 Analysis of the single player and multiplayer modes

At the end of the questionnaire presented to the subjects, they were asked some more specific questions regarding some of the games developed.

Regarding the single player and multiplayer modes, 63.6% said they liked the multiplayer versions and 81.8% considered this mode to be more challenging.

As for the Arithmetic game, most of the subjects affirm that they like the interaction more by mouse (58.6%), with only 25.9% preferring voice interaction and 15.5% did not notice any difference. This is also the most challenging interaction modality (53.4%).

The multiplayer mode of the Sorting game was presented with and without handicapping mechanism. The subjects considered the version with handicap more challenging (27.3%) and 50% of the subjects affirmed not to notice differences.

Subjects choose the competitive approach as their preferred (59.1%) and as the most challenging (63.6%). Both approaches convince the same number of subjects regarding fun, 45.5% choose the competition and 45.5% choose the collaboration. The remaining did not notice any difference. Regarding the incentive to the interaction between users, 81.8% choose the collaborative approach.

7.3.3.6 Analysis of SUS and IMI questionnaires

The SUS questionnaire was used to evaluate the usability of the whole platform. The SUS instrument is quoted from 0 to 100. A score below 70 means that the system presents usability problems and more than 71.4 classifies the system as having good usability [348]. There were significant differences ($P = 0.046 < 0.05$) with respect to age (<30 years, >30 years) of users, and the values of the questionnaire were significantly higher in participants with more than 30 years (39.78 vs. 27.61). The results observed in this study (88.7%) indicate that the platform has a positive assessment in relation to its usability. More specifically, it can be stated that the platform offers good usability.

The SUS score results were also compared using the two independent samples. Table 22 presents the mean and standard deviation of the SUS score obtained by the classroom and online tests samples.

Table 22 - SUS and IMI results by classroom and online tests

Classroom test		**Online test**	
SUS score	IMI score	SUS score	IMI score
90.2; 9.5	90.9; 9.1	87.1; 12.0	83.0; 13.5

The mean value is higher in the classroom test (90.2%), however still very good when the individuals did the test online (87.1%). Applying the Mann-Whitney test (p value 0.45) there was no statistical evidences of the difference between the usability results on the tests conducted online and in the classroom.

Figures 114 and 115 show the SUS answers distribution about the classroom and online tests, respectively.

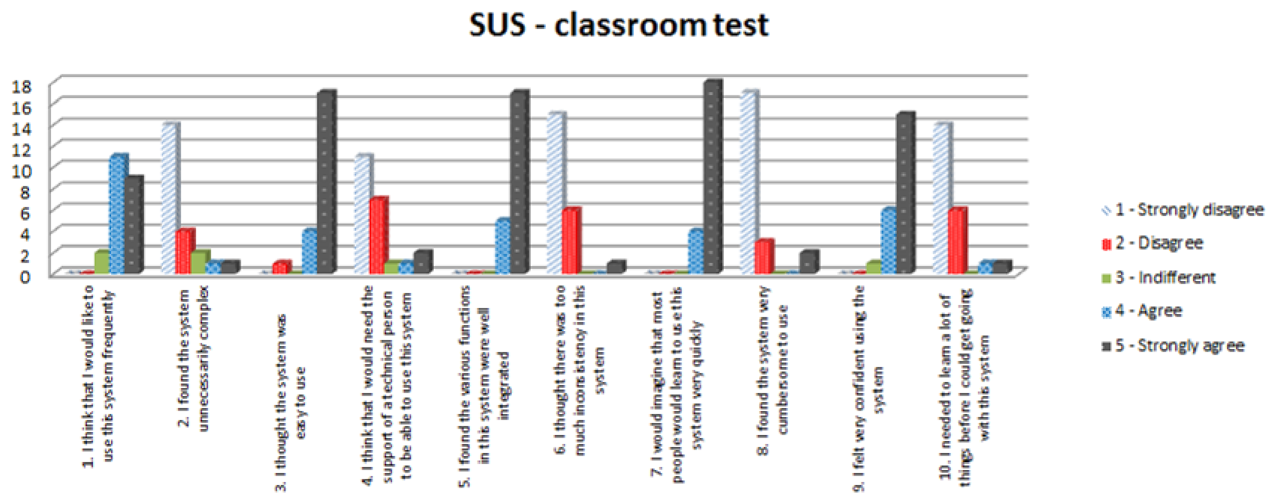


Figure 113 - SUS answers distribution - classroom test

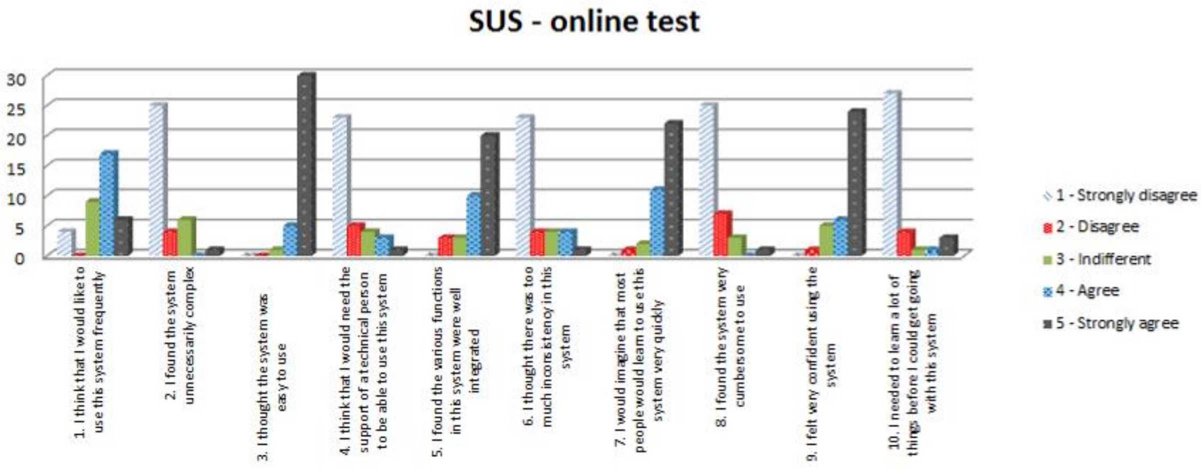


Figure 114 - SUS answers distribution – online test.

The answers distribution confirms the good level of concordance in terms of usability of the overall system.

It was used in this research one scale of the IMI questionnaire, to assess the interest and satisfaction of individuals in relation to all the contact they had with the Rehab+ platform (Table 22). The total result (87.0%) shows that users were satisfied with the platform and that it aroused their interest. Most users answered that they would like to use this platform often (74.2%) and 94.8% answered they liked to participate in this activity and that it was fun. The mean value of IMI score is also higher in the classroom test (90.9%), however still very good when the individuals did the test online (83.0%).

Applying the Mann-Whitney test (p value 0.015) reveals that there was statistical evidence of the difference between the IMI distribution results by playing online and in the classroom.

Figures 116 and 117 show the IMI answers distribution about the classroom and online tests, respectively.

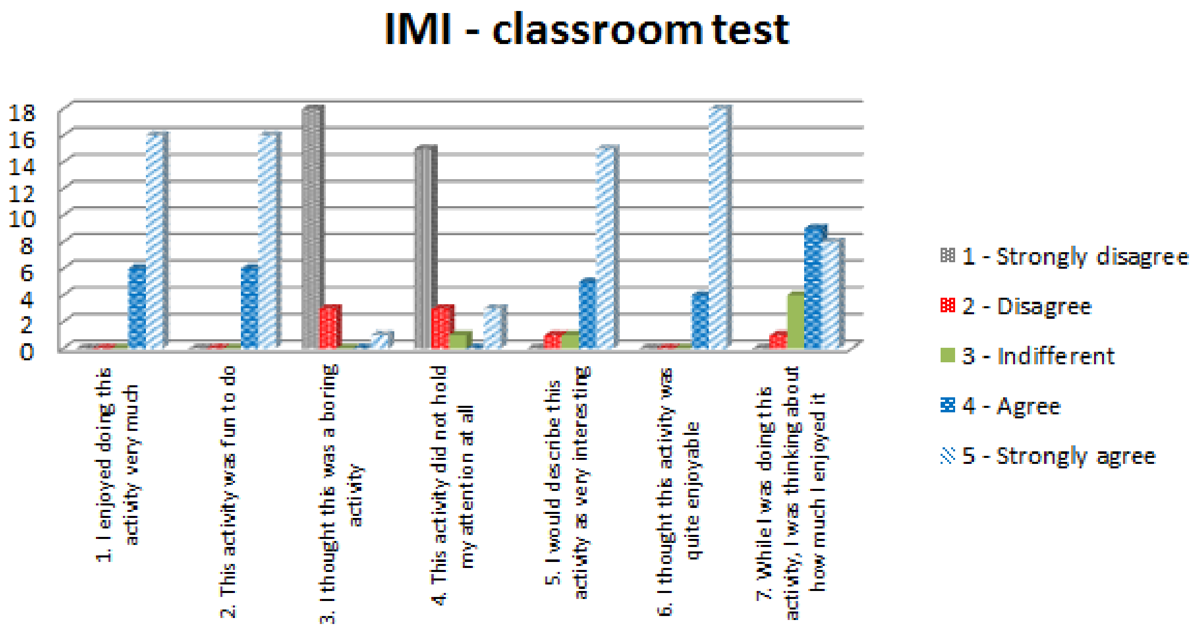


Figure 115 - IMI answers distribution – classroom test.

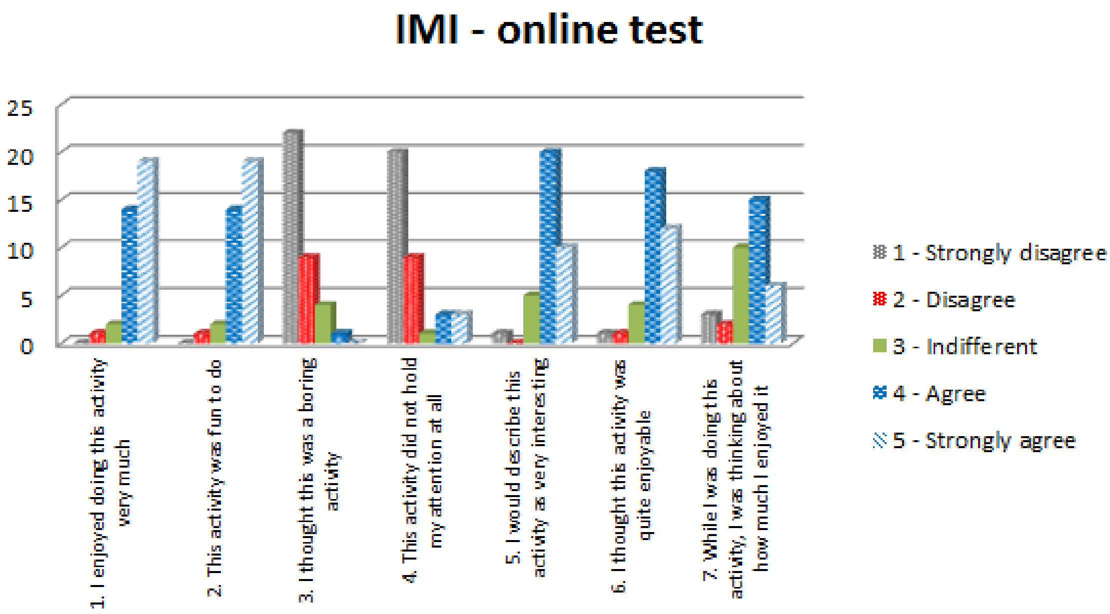


Figure 116 - IMI answers distribution – online test.

The IMI answers distribution also reveals that most of individuals considered playing the games was very enjoyable and fun, regarding doing the tests online or in the classroom.

These results show the motivation and the interest of the participants by playing these games.

7.3.4 Conclusions

The main objective of this work was make a preliminary study about the inclusion of a set of features that can contribute to innovate the cognitive therapy processes, making them more motivating for patients.

Tests were carried out on a sample of healthy subjects and without significant limitations. The usability of the platform was evaluated, resulting in a positive assessment. Also, it was assessed the interest and satisfaction of individuals in relation to all the contact they had with the Rehab+ platform and the total result showed that users were satisfied with the platform and that it aroused their interest. The distribution of users' answers revealed that most of them considered that playing the games was very enjoyable and fun.

The main limitations presented in this work are related with the sample size and the population of the individuals, since they do not present any physical or cognitive limitation. However, for a preliminary assessment of the usability of a game that integrates social features such as cooperation, competition, and handicapping, and enables user interaction via mouse and voice commands, the results show a promising way for the rehabilitation of users.

7.4 Rehab+ - Usability Study with Elderly Users

The tests described here were designed primarily to evaluate the usability and attractiveness of the games of Rehab+ Platform, to see if they are easy to play and interact, if it is easy to understand what is asked in each of them, if users like the games and if these are appealing. The tests were done in the nursing home "Santa Casa da Misericórdia" in Vila Verde. This experiment included the participation of five elderly users' volunteers.

7.4.1 Procedure

Five games were tested in an evaluation session as is described below. The games tested were: Sorting game, Arithmetic game, Arithmetic using Voice, Memory for Words game, and Attention-Concentration game.

The participants were asked to take part in this experiment during their regular recreational/playful activities undertaken at the nursing home.

The experiment began with a short explanation of the purpose of the experiment, the procedure, the games they would play, the purpose of these games, and what was expected from the subjects.

After their full consent to participate was obtained by the nursing home staff, each subject read and signed an informed consent form (Annex C), which contained all the information regarding the research and testing in which they would participate.

Then a questionnaire (Annex D) was filled out of pre-selection and characterization regarding the subjects' age, gender, education level, motor and cognitive difficulties, and familiarity with technology and games.

The subjects were seated in front of the laptop screen and before playing each game, they were introduced to the game and the interaction style by giving them a short demonstration of how to play the game, and how to interact, accompanied by verbal explanations. After that, they were given the possibility to practice playing the game to familiarize themselves with the gameplay, the input mechanisms, game elements and goals of the game.

Each of the games has a first screen that contains a small description that clarifies about the goal and the rules of the game. These instructions were read in conjunction with the subject, before the subject started playing each game. The tests in this evaluation included only games in single player version.

Table 23 presents the timetable for this one session experiment.

Table 23 - Experiment timetable

Game #1 - Sorting	
Intro and explanation of the game	1 min
Game experimenting	2 mins
Session#1 of play – sorting game	1.5 mins
Session#1 of questions	5 mins
Game #2 – Attention-concentration	
Intro	1 min
Game experimenting	1 min
Session#1 of play – attention-concentration game	2 mins
Session#1 of questions	5 mins
Game #3 – Memory for Words	
Intro	1 min
Game experimenting	2 mins
Session#1 of play – memory for words game	6 mins
Session#1 of questions	5 mins
Game #4 - Arithmetic	
Intro	1 min
Game experimenting	2 mins
Session#1 of play – arithmetic game	6 mins
Session#1 of questions	5 mins
Game #5 – Arithmetic Voice	
Intro	1 min
Game experimenting	1 mins
Session#1 of play – arithmetic voice	6 mins
Session#1 of questions	5 mins
Post-Game Discussion and Debriefing	3 mins

Subjects started to play one single player game at a time. They were given suggestions of what was the order to follow for the games they had to play, but they could also play them in a random order. Our suggestion consisted in that the subject could start by the sorting game, followed by the attention-concentration game, memory for words game, arithmetic game, and arithmetic voice game.

After playing each game, the subject had to fill out a questionnaire about the game (Annex E). The questionnaire contained selected questions from the IMI questionnaire. After playing all the five games, the subject was asked additional questions about the mood, challenges, which game was his favorite, the overall experience and some questions related with usability of the games.

Each subject played the games during approximately 30 minutes where the total activity (including evaluation) had a duration of approximately 1 hour and 15 minutes. The experimental setup is shown in Figure 117.

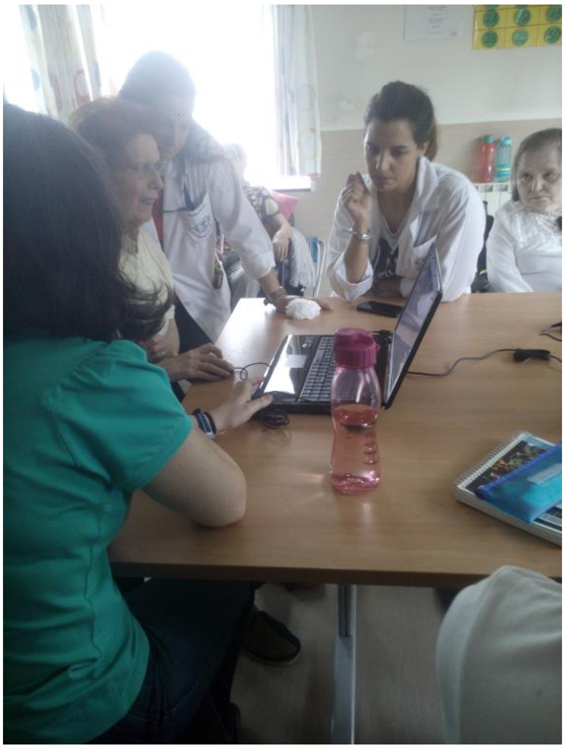


Figure 117 – A participant playing the games.

7.4.2 Instruments used

For this experiment were used two questionnaires: a questionnaire of pre-selection (Annex D) and characterization of the participants and a questionnaire for evaluating the participants' game experience (Annex E) with each game. In Annex E we only present the questionnaire for the sorting game (and its variations). For the other games included in Rehab+ platform, the questionnaire about Game Experience would be similar. A questionnaire (Annex F) after playing all the games (including the multiplayer games) was planned to use in the second session and is also here described.

Questionnaire of Pre-Selection

This questionnaire (Annex D) has an initial section, which aims to make a characterization of the sample in terms of age, gender and education, among others.

Questionnaire about Game Experience with each game

It was developed a questionnaire (Annex E) that was applied to all subjects who participated in the test. The questionnaire uses one validated instrument, commonly used in testing computer games, the IMI (Intrinsic Motivation Inventory). IMI is a multidimensional assessment tool that evaluates the subjective experiences of the participants in relation to the activity they experienced which, in this case, is in relation to the subjects experience with each game. It measures four scales: interest/enjoyment, perceived competence, effort/importance, and pressure/tension.

We adapted this instrument in order to use only 20 statements (5 per scale), as is used in Goršič et al. (2017)[349]. Participants rate how true each statement is on a 7-point scale, with 1 indicating "not at all true" and 7 indicating "very true". The possible range for each scale is therefore 5–35.

Post-Game Discussion/Debriefing

After subjects fill out the questionnaire about each game we ask them to give impressions about the game and in this conversation, we ask them also about some aspects related to questions included in CEGEQ and SUS questionnaire such as:

- Did you liked the game scenario?
- Did you find the game scenario interesting?
- Did you like the design of the game?
- Would you like to play again?
- Did you find the game ease to play?

Post-Experiment Questionnaire

This is the questionnaire planned to fill out after playing all the games of Rehab+ Platform (single player and multiplayer).

In this questionnaire, subjects are asked to compare all the games. It consisted of questions we used in our previous study with healthier users and adds also a group of 8 questions, which focus on the same four aspects of subjective experience as the IMI, but explicitly asks participants to compare all the games. We adopt here these group of questions as used in overall game experience questionnaire of Goršič et al. (2017)[349]. According to these authors, IMI is poor at identifying differences between similar games.

The eight questions added are:

- What was your favorite game? Why?
- What was your least favorite game?
- Which game did you put the most effort into?
- Which game did you put the least effort into?
- Which game did you feel the most competent at?
- Which game did you feel the least competent at?
- Which game was the most stressful?
- Which game was the least stressful?

As mentioned before, in addition to the previous questions, we considered also the questions that specifically address a comparison between the games modes and forms of interaction and an open response space to collect any comments that users want to express, as we use in our previous study with healthier users.

7.4.3 Results

In this section, the results of the questionnaires about each game experience answered by the elderly users involved in the tests of the Rehab + platform are analyzed. The questionnaires were analyzed using the Microsoft Excel software, in which were inserted the answers and the statistical analysis was performed. Statistical measures such as mean and standard deviation were applied to characterize the sample.

7.4.3.1 Sample Characterization

Table 24 shows a summary characterization of the sample that participated in the tests on the Rehab + platform in Vila Verde.

Table 24 - Characterization of the sample

	Sample (N = 5)			
	n	%	*Mean*	*Std*
Gender				
Female	4	80.0		
Male	1	20.0		
Age			76.4	2.70
Categorized Age				
< 80	4	80.0		
>= 80	1	20.0		

Education Level		
Higher Education	0	0
Non-higher education	5	100.0
Cognitive Problems		
Yes	1	20.0
No	4	80.0
Motor Problems	3	
Yes	3	60
No	2	40
Handedness		
Right handed	5	100
Left-handed	0	0
Color Blindness		
Yes	0	0
No	5	100
Do you use regularly the computer?		
Never	5	100
Rarely (once for month)	0	0
Sometimes (one time per week)	0	0
Often (Every day, 1 hour or less)	0	0
Always (everyday over an hour)	0	0
Do you regularly play computer games?		
Yes	0	0
No	5	100

Table 25 presents the characteristics of the sample and mean and standard deviation of the respective age.

Table 25 - Sample characterization

Gender (Females; Males)	Age (mean; std)	Cognitive problems (yes; no)	Motor Problems (yes; no)	Education Level (Basic/High School/BSc/MSc/PhD)
4; 1	76.4; 2.7	1; 4	3;2	5; 0; 0; 0; 0

Five people participated in these tests, of which four were female and one male. Participants have a mean age of 76.4 years and the total sample varies between 74 and 81.

Regarding education, all the participants concluded Basic education (1st cycle). All the subjects are right-handed. None of the participants suffers from color blindness. Three of the participants have motor difficulties, of which two move in a wheelchair and the other with the help of a crutch. One of the participants reported suffering from Alzheimer disease.

All the participants stated have never used a computer or the mouse and never played computer games.

7.4.3.2 *Qualitative Observations*

The most frequently chosen favorite game was attention-concentration, and it was the most frequently chosen as the one requiring the less effort.

The participant with Alzheimer disease mentioned the fact that her favorite game was the sorting game because she knows and understand numbers very well. She added that she also liked very much of the attention-concentration game because of the colors and the images.

The other four participants chosen the attention-concentration game as their favorite game because they liked the images and the colors very much.

The participants reported they liked the games interface and found it simple and also they found the game scenario interesting.

Regarding the rules of the games, they found that they were easy to understand after the instructions given in the game and the introduction and demonstration of the game.

Globally all the participants reported that they liked playing all the games, they liked all the games and that they found the games easy to use and challenging despite the many problems in the beginning in using the mouse since they never used a computer or a mouse before.

One of the participants wanted to stop playing after playing the sorting, attention-concentration game. He reported that it happens frequently that he feels some anxiety and confusion when he sees many people around in the living room.

All the participants reported they would like to play again all the games.

7.5 Summary

This chapter presented all the experiments performed in order to provide scientific evidence that it is possible to use serious games for health rehabilitation to increase the motivation of users. Experiments were conducted with healthy people and elderly users. The scores achieved in all the tests used were quite good with emphasis for the very good SUS and IMI scores achieved.

Chapter 8

Conclusions and Future Work

Serious games design is a recent and active multidisciplinary research area. Making use of game design methodologies, storytelling and narrative structure, visual arts, interaction paradigms and modalities and other methodologies and paradigms commonly used in computer games, is proven to be effective in applications whereas entertainment is not their main purpose. This effectiveness arises from several game characteristics such as providing higher levels of user engagement and motivation, a clear definition of long term and short-term goals to achieve and a rewarding mechanism, both contributing to the individual sense of achievement and progress and also for the social recognition of these achievements. The use of simulation is also a main benefit, reducing costs and providing a controlled and safe environment to the users.

Our research work focused on serious games for health rehabilitation. From the literature review in this area we found that, although there exist many and recent serious games reported in the literature, rehabilitation games have not yet fully exploited most of the entertainment features that games can provide. A main avenue of our research reposted in this thesis was to deep study the domain of Serious Games for Health Rehabilitation and make a systematic characterization of the reported games and their features that enabled us to identify those features that deserve further research effort to attain higher levels of motivation in rehabilitation programs. Thus, a main focus of the herein presented work was to identify and measure the impact of the more relevant aspects that can improve the suitability and effectiveness of a game for rehabilitation.

As another major research opportunity we have tackled is concerned with the study of how the effectiveness of computer games for rehabilitation can be increased by the incorporation of a social dimension. There is very few reported work for systems where collaboration or competitiveness performs a major role regarding to the rehabilitation process. The ability to make games playable by several patients (for this purpose, an individual with some degree of disability) or between patients and healthy users, was also identified as very relevant feature that we studied and made some contributions.

Current technological development also allows that most of these games can be deployed in affordable platforms suitable for being used at home with remote monitoring by therapists. This way, user displacement costs and associated discomfort may be reduced by enabling that parts of the rehabilitation program to be conducted at their home.

A major result of this work is the proposal of a serious game for health rehabilitation taxonomy that provides the research community with a tool to fully characterize serious games. Additionally, we have also proposed a Serious Game Framework, identifying and describing the components and software architecture to make possible to implement instances of serious games for health rehabilitation according to our previous research focused on the improvement of the rehabilitation process.

Using the proposed framework a main outcome was the development of prototypes and a web-based system composed of 12 web games that can be used to train cognitive functions (memory, attention and concentration, calculus) and that records the results of the users actions in the execution of the games in order for this data be later analyzed. The games have implemented a set of features such as competition, collaboration, handicap mechanisms and also natural user interfaces. We conducted several experiments with users in order to test and validate our approach, namely regarding usability, motivation and engagement. Results proven to be very positive showing that the games have high level of usability and that the proposed social features increase users motivation and engagement.

With this thesis we have attained innovative contributions to serious games for rehabilitation such as: design guidelines, a taxonomy, design of software frameworks and tools, game modules, a small set of serious games, and user testing procedures and results, that can contribute to the development of more effective serious games for rehabilitation programs in the future.

8.1 Main Conclusions and Contributions

Addressing our research question, this thesis adds the following contributions.

- We have conducted a comprehensive review of the literature concerning games for health rehabilitation and identify current trends. We concluded that the adoption of Serious Games as been increasing in the last decades. A significant number of the reported research refers to prototypes and to games in early stages of development and testing. Furthermore, there are few examples where a significant sample of real patients was used to validate the proposed approaches. Consequently, definitive conclusions about their effectiveness are hard to take and must be validated by further research. Most of the games are designed as for single user activities. Recently, more reports on multiplayer games where the collaboration and competitiveness facility exists, but the evaluations done are inexistent (yet planned for future studies), or conducted with a very small number of patients. Nevertheless, all of these works refer to progress monitoring, performance feedback and adaptability.

- An initial survey and proposed Serious Game classification towards a taxonomy was proposed. This work was presented and published [89] and has been widely adopted by the research community having, as of end of May 2017, 230 citations at Google Scholar[1] and 132 citations at SCOPUS. As referred, some authors have been adopting our proposed classification and some other extending the proposed taxonomy [90].
- Based on our research and also on the analysis of the contributions made by others researchers, we proposed and extended taxonomy for health rehabilitation games.
- We have also identified that, in general, and besides the mechanisms associated with the adoption of a given taxonomy, there were not reported validation mechanisms for the proposals. We designed a mechanism in order to validate our proposal. The taxonomy was validated using a questionnaire addressed to a sample of researchers and professionals with experience and expertise in domains of knowledge interrelated with Serious Games for Health Rehabilitation, such as Computer Graphics, Game Design, Interaction Design, Computer Programming and Health Rehabilitation. Our proposal was positively evaluated by the sample that indicated that they found it useful and could use it to classify / compare their own serious games. Although positive, "ease of use" and "ease of extension", presented the lowest values of this evaluation. During this process, researchers made some suggestions to the proposal. This feedback was analyzed and a final and revised version of the taxonomy was devised and presented.
- We devoted particular attention to the major input modalities associated to the use of natural user interfaces, in a description focused in the technology main goals, main applications and finally its application in the rehabilitation domain. Our main conclusions are that most of these games present simple interfaces and traditional forms of interaction. Also, natural user interfaces are exploited in some recent games, but are poorly evaluated in terms of the rehabilitation process. Recent technological developments encourage us to study and propose the adoption of more input modalities, making the games more adaptable to different users needs and giving to them, in conjunction with a better user experience, a more effective rehabilitation [112].
- Additionally, we have also identified that social interaction is poorly exploited in SGHR and few games present or study a social dimension. Competition, collaboration

[1] https://scholar.google.pt/citations?view_op=view_citation&hl=pt-PT&user=wlBRqCoAAAAJ&citation_for_view=wlBRqCoAAAAJ:u5HHmVD_uO8C

and handicapping were identified as fundamental issues in this social dimension. We noticed that there was very few reported work for systems where collaboration or competitiveness performs a major role regarding to the rehabilitation process. The social component intends to increase motivation by allowing patients to play against or with other patients or even with healthy users such as friends or family. This allows the rehabilitation process to be more participated and inclusive. The described handicap mechanism is crucial to allow different players (with different abilities / disabilities) to have a fairly game experience [90].

- We proposed a framework for the development of serious games in health rehabilitation. This framework was designed based on our in depth research that enabled the identification of a set of important features that, in general, a Serious Game may exhibit. These features are related to several aspects of the game, such as the interaction modalities, social interaction such as competition, collaboration and handicapping, the possibility to use them at home remotely monitored by therapists, reducing costs and discomfort associated with the transportation [114, 350, 351].
- We implemented instances of this proposed framework in order to test and validate our contributions. Examples were the prototypes and study regarding NUI [104, 111].
- Another implemented instance of the framework was the Rehab+ web platform where games comprising competition, collaboration and handicapping were developed [91, 342].
- Initial tests were carried out on a sample of healthy subjects and without significant limitations. The usability of the platform was evaluated, resulting in a positive assessment. Also, it was assessed the interest and satisfaction of individuals in relation to all the contact they had with the Rehab+ platform and the total result showed that users were satisfied with the platform and that it aroused their interest. The distribution of users' answers revealed that most of them considered that playing the games was very enjoyable [343, 344].
- The set of games developed under the Rehab+ platform was also tested with elderly users which provided us with important results and insights regarding the interaction, usability and satisfaction. These users have, in general, low levels of technological experience with computational devices and they are not usual game players. Additionally some of them present similar needs regarding cognitive rehabilitation / training as traditional patients. Results were positive and encourage further development of our proposals.

8.2 Limitations

The main limitations presented in this work are related with the sample size and the population of the individuals, since in the main tests of the platform they do not present physical or cognitive limitations. The tests were done mostly with healthier users although also with elderly users.

Another limitation is that games were designed without the collaboration of a therapist and therefore the game tasks are not completely validated in therapeutic terms.

However, for a preliminary assessment of the usability of a game that integrates social features such as collaboration, competition, and handicapping, and enables user interaction via mouse and voice commands, the results show a promising way for users' rehabilitation.

8.3 Future Work

The perspectives for future work are related mostly with the system and its application:

- Validate the games with therapists and make a larger set of experiments with elderly users and patients with cognitive impairments and in cognitive rehabilitation after an accident or stroke;
- Develop a larger set of games transforming Rehab+ into a complete rehabilitation platform;
- Perform a more in-depth study of natural interaction schemes and improve the feedback mechanisms in the games;
- Develop an interface application for the patient to choose the training session for each day and see the results, for results analysis and users registration, configuration of therapy program with the schedule of the games they would have to train at each session;
- Implement more games with similar logic that vary only in the feature we want to test, in order to compare the results obtained.
- Developed more sophisticated algorithms for automatic handicap configuration based on machine learning algorithms.

The development of this future work may enable the use of the platform developed for real cognitive rehabilitation tasks with real patients in the future.

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Annexes

- **Annex A** – SGHR Extended Taxonomy Validation Questionnaire
- **Annex B** – Rehab+ Questionnaire - Usability, Motivation and Experience (study with Healthy users)
- **Annex C** – Rehab+ - Informed consent form (study with Elderly users)
- **Annex D** – Rehab+ Questionnaire A – Pre-Selection (study with Elderly users)
- **Annex E** – Rehab+ Questionnaire B – Subjective Experience with the Game (study with Elderly users)
- **Annex F** – Rehab+ Questionnaire C – Post-Experiment (study with Elderly users)
- **Annex G** - Work Plan

Annex A – SGHR Extended Taxonomy Validation Questionnaire

SGHR – Extended Taxonomy Validation Questionnaire

Validation of a Taxonomy of SGHR

The purpose of this survey is to validate the interest and applicability of a taxonomy proposed for the classification and comparison of Serious Games for Health Rehabilitation (SGHR). The proposed taxonomy is multi-dimensional. It is composed of a set of 12 dimensions that as a whole will be used to classify a particular Serious Game.

Este inquérito tem por objetivo a validação do interesse e aplicabilidade da Taxonomia proposta para a Classificação e comparação de Jogos Sérios na área da reabilitação da Saúde. A Taxonomia proposta é multidimensional. É composta por um conjunto de 12 dimensões que no seu todo serão usadas para classificar um determinado jogo.

Data regarding the identification of participants in this study is confidential and anonymity will be maintained. If you wish to be informed about the results of the survey, please fill in your e-mail.

1. Identification

1.1. Full Name

____

1.2. Your e-mail

____

1.3. Gender

____

1.4. Your Age

____

1.5. Your Job/Work Area

____

1.6. Your Area of Specialization

____

1.7. Choose the option that you consider most appropriate for your case.

	Very Low	Low	Moderate	High	Very High
Frequency of computer use.	○	○	○	○	○
Frequency of Smartphones / Tablets usage.	○	○	○	○	○
Frequency with which you play PC games.	○	○	○	○	○

Frequency with which you play Games on Smartphones / Tablets.	◯	◯	◯	◯	◯
Frequency with which you play Games in Consoles.	◯	◯	◯	◯	◯
Frequency with which You play Serious Games.	◯	◯	◯	◯	◯

1.8. Choose the option that you consider most appropriate for your case.

	Very Low	Low	Moderate	High	Very High
Experience in Video Games Design.	◯	◯	◯	◯	◯
Experience in Interaction.	◯	◯	◯	◯	◯
Experience in Computer Graphics.	◯	◯	◯	◯	◯
Experience in Programming.	◯	◯	◯	◯	◯
Experience in the Health / Rehabilitation area.	◯	◯	◯	◯	◯

2. Proposed Taxonomy

Due to the complexity and variability of Serious Games in Health Rehabilitation Area (SGHR), the upper layer of our taxonomy is divided in 12 dimensions/criteria presented in Figure 1 and described in Table 1. All the dimensions contribute to characterize a SGHR.

To each dimension can be associated a set of possible types or values. In some dimensions, we can have more than one available type or value. We indicate this by using the term “mixed”. For instances, the criterion “Interaction Goal” in "Game Players" dimension can have the value: competitive and collaborative. Mixed means that a game can have either or both two values.

If you cannot see properly the figure, you can use CTRL plus '+' to zoom in.

Figure 118 - Proposed Taxonomy of SGHR.

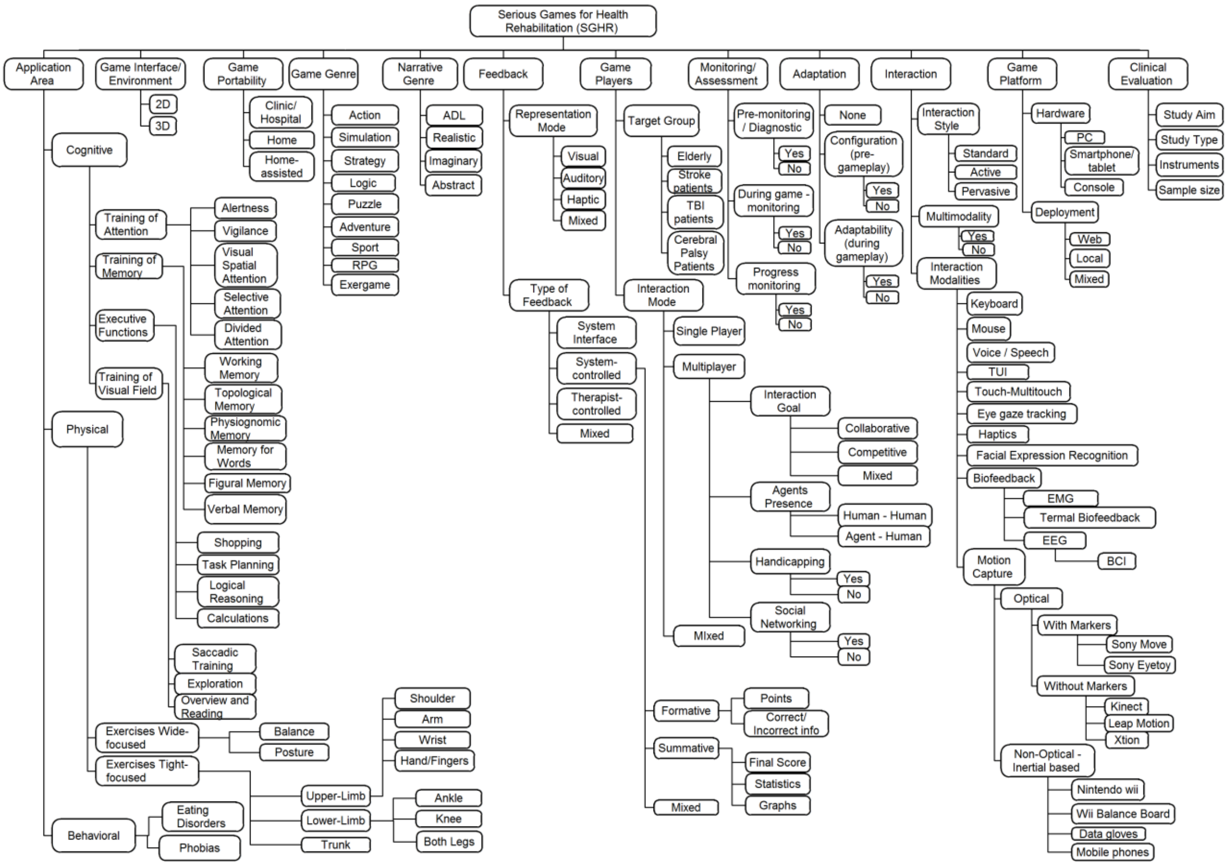

Table 26 - Description of the Dimensions/Criteria.

Dimension / Criterion	Description
Application Area / Área de aplicação:	Refers the domain application of the serious game. It can be divided in: Cognitive, Physical and Behavioral.
Game Interface/ Environment:	Game graphical interface is the dimensionality of the game environment interface. It can be two-dimensional (2D) or three-dimensional (3D).
Game Portability:	Game portability is related with the capability of the system to be used at home, or at a hospital/clinic, or at home with assistance of a therapist. The term Home-assisted is used to represent the games that can be played at home but also require the assistance of a therapist.
Game Genre:	The game genres considered are: Action, Simulation, Strategic, Logic, Puzzle, Adventure, Sport, RPG, and Exergame.
Narrative Genre:	Refers to the thematic content of the task the patient has to do in a rehabilitation session. We divide the criterion in the following values: Activities of daily living (ADL), Realistic, Imaginary, and Abstract.
Feedback:	Refers to the response of the game system to the player actions and is used to guide the patients about the adequacy of their performance and how to improved it. It can be: - System Interface Feedback: the system reacts to the actions of the player and responds accordingly, the changes in the system interface will give the player hints about the effect of their last actions and how he could continue; - System-controlled Feedback: this involves conveying hints on the patient's progress during the game, by, for example, presenting scores based on the performance of the player in the game; - Therapist-controlled Feedback: involves comments, advice and other therapy techniques that the therapist might apply with the patients as a complement to the system-controlled feedback and to the game therapy.
Game Players:	Includes the target group (to whom the game system is intended for such as: elderly, post-stroke patients, etc.) of the players and the interaction mode (single player or multiplayer mode) in gameplay.
Monitoring/ Assessment:	In order to give feedback, the patient's performance in relation to the defined task goals has to be monitored/assessed. This monitoring can be done by the game (fully automated), the therapist (manual), or a combination of both (semi-automated). Monitoring can be done before gameplay (Diagnostic), during gameplay (During Game-Monitoring) or after gameplay (Progress Monitoring).
Adaptation:	The game system can have an adaptation mechanism done before gameplay (Configuration), during gameplay (Adaptability) or no adaptation (None).
Game Platform:	Can refer the Hardware architecture (the physical components of the game system) and the Game Deployment (environment on which the game runs: Web, Local or a combination of the two previous values).
Interaction:	Includes: interaction style (standard, active, pervasive), presence of multimodality (refers to the existence of an interface multimodal, that is, an interface that allows the possibility of having more than one input modality that can be selected, according to the patient abilities), and interaction modalities.
Clinical Evaluation:	Includes the user tests done with the game system. For each study it is important the study aim, the study type (randomized control trial, pilot study, case control study, review, usability study, etc.), the instruments of measurement used and the number of participants.

3. Taxonomy Criteria evaluation

3.1. Regarding the relevance of the "Application Area" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Application Area / Área de aplicação:	Refers the domain application of the serious game. It can be divided in: Cognitive, Physical and Behavioral.

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Application Area	○	○	○	○	○
- Cognitive	○	○	○	○	○
--Training of Attention	○	○	○	○	○
--Training of Memory	○	○	○	○	○
--Executive Functions	○	○	○	○	○

--Training of Visual Field	◯	◯	◯	◯	◯
- Physical	◯	◯	◯	◯	◯
-- Exercises Wide-focused	◯	◯	◯	◯	◯
--- Balance	◯	◯	◯	◯	◯
--- Posture	◯	◯	◯	◯	◯
-- Exercises Tight -focused	◯	◯	◯	◯	◯
--- Upper-Limb (shoulder, arm,wrist, hand/fingers)	◯	◯	◯	◯	◯
--- Lower-Limb (ankle, knee, both legs)	◯	◯	◯	◯	◯
--- Trunk	◯	◯	◯	◯	◯
- Behavioral	◯	◯	◯	◯	◯
-- Eating Disorders	◯	◯	◯	◯	◯
-- Phobias	◯	◯	◯	◯	◯

3.2. Regarding the relevance of the "Game Interface / Environment" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Game Interface/ Environment:	Game graphical interface is the dimensionality of the game environment interface. It can be two-dimensional (2D) or three-dimensional (3D).

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Game Interface/Environment	◯	◯	◯	◯	◯
- 2D	◯	◯	◯	◯	◯
- 3D	◯	◯	◯	◯	◯

3.3. Regarding the relevance of the "Game Portability" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Game Portability:	Game portability is related with the capability of the system to be used at home, or at a hospital/clinic, or at home with assistance of a therapist. The term Home-assisted is used to represent the games that can be played at home but also require the assistance of a therapist.

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Game Portability	◯	◯	◯	◯	◯
- Clinic/Hospital	◯	◯	◯	◯	◯
- Home	◯	◯	◯	◯	◯
- Home-Assisted	◯	◯	◯	◯	◯

3.4. Regarding the relevance of the "Game Genre" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Game Genre:	The game genres considered are: Action, Simulation, Strategic, Logic, Puzzle, Adventure, Sport, RPG, and Exergame.

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Game Genre	○	○	○	○	○
- Action	○	○	○	○	○
- Simulation	○	○	○	○	○
- Strategy	○	○	○	○	○
- Logic	○	○	○	○	○
- Puzzle	○	○	○	○	○
- Adventure	○	○	○	○	○
- Sport	○	○	○	○	○
- RPG	○	○	○	○	○
- Exergame	○	○	○	○	○

3.5. Regarding the relevance of the "Narrative Genre" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Narrative Genre:	Refers to the thematic content of the task the patient has to do in a rehabilitation session. We divide the criterion in the following values: Activities of daily living (ADL), Realistic, Imaginary, and Abstract.

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Narrative Genre	○	○	○	○	○
- ADL	○	○	○	○	○
- Realistic	○	○	○	○	○
- Imaginary	○	○	○	○	○
- Abstract	○	○	○	○	○

3.6. Regarding the relevance of the "Feedback" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Feedback:	Refers to the response of the game system to the player actions and is used to guide the patients about the adequacy of their performance and how to improved it. It can be: - System Interface Feedback: the system reacts to the actions of the player and responds accordingly, the changes in the system interface will give the player hints about the effect of their last actions and how he could continue; - System-controlled Feedback: this involves conveying hints on the patient's progress during the game, by, for example, presenting scores based on the performance of the player in the game; - Therapist-controlled Feedback: involves comments, advice and other therapy techniques that the therapist might apply with the patients as a complement to the system-controlled feedback and to the game therapy.

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Feedback	○	○	○	○	○
- Representation Mode	○	○	○	○	○
-- Visual	○	○	○	○	○
-- Auditory	○	○	○	○	○
-- Haptic	○	○	○	○	○
-- Mixed	○	○	○	○	○
- Type of Feedback	○	○	○	○	○
-- System Interface	○	○	○	○	○
-- System-controlled	○	○	○	○	○
--- Formative	○	○	○	○	○
----Points	○	○	○	○	○
---- Correct/Incorrect responses	○	○	○	○	○
--- Summative	○	○	○	○	○
---- Final Score	○	○	○	○	○
---- Statistics	○	○	○	○	○
---- Graphs	○	○	○	○	○
--- Mixed	○	○	○	○	○
-- Therapist-controlled	○	○	○	○	○
-- Mixed	○	○	○	○	○

3.7. Regarding the relevance of the "Game Players" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Game Players:	Includes the target group (to whom the game system is intended for such as: elderly, post-stroke patients, etc.) of the players and the interaction mode (single player or multiplayer mode) in gameplay.

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Game Players	○	○	○	○	○
- Target Group	○	○	○	○	○
-- Elderly	○	○	○	○	○

-- Stroke Patients	◯	◯	◯	◯	◯
-- TBI Patients	◯	◯	◯	◯	◯
-- Cerebral Palsy Patients	◯	◯	◯	◯	◯
- Interaction Mode	◯	◯	◯	◯	◯
-- Single Player	◯	◯	◯	◯	◯
-- Multiplayer	◯	◯	◯	◯	◯
--- Interaction Goal	◯	◯	◯	◯	◯
---- Collaborative	◯	◯	◯	◯	◯
---- Competitive	◯	◯	◯	◯	◯
---- Mixed	◯	◯	◯	◯	◯
--- Agents Presence	◯	◯	◯	◯	◯
---- Human-Human	◯	◯	◯	◯	◯
---- Agent-Human	◯	◯	◯	◯	◯
--- Handicapping	◯	◯	◯	◯	◯
---- Yes	◯	◯	◯	◯	◯
---- No	◯	◯	◯	◯	◯
--- Social Networking	◯	◯	◯	◯	◯
---- Yes	◯	◯	◯	◯	◯
---- No	◯	◯	◯	◯	◯
-- Mixed	◯	◯	◯	◯	◯

3.8. Regarding the relevance of the "Monitoring/Assessment" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Monitoring/ Assessment:	In order to give feedback, the patient's performance in relation to the defined task goals has to be monitored/assessed. This monitoring can be done by the game (fully automated), the therapist (manual), or a combination of both (semi-automated). Monitoring can be done before gameplay (Diagnostic), during gameplay (During Game-Monitoring) or after gameplay (Progress Monitoring).

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Monitoring/Assessment	◯	◯	◯	◯	◯
- Pre-monitoring/Diagnostic	◯	◯	◯	◯	◯
-- Yes	◯	◯	◯	◯	◯
-- No	◯	◯	◯	◯	◯
- During Game-monitoring	◯	◯	◯	◯	◯
-- Yes	◯	◯	◯	◯	◯
-- No	◯	◯	◯	◯	◯
- Progress Monitoring	◯	◯	◯	◯	◯

-- Yes	◯	◯	◯	◯	◯
-- No	◯	◯	◯	◯	◯

3.9. Regarding the relevance of the "Adaptation" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Adaptation:	The game system can have an adaptation mechanism done before gameplay (Configuration), during gameplay (Adaptability) or no adaptation (None).

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Adaptation	◯	◯	◯	◯	◯
- None	◯	◯	◯	◯	◯
- Configuration (pre-gameplay)	◯	◯	◯	◯	◯
-- Yes	◯	◯	◯	◯	◯
-- No	◯	◯	◯	◯	◯
- Adaptability (during gameplay)	◯	◯	◯	◯	◯
-- Yes	◯	◯	◯	◯	◯
-- No	◯	◯	◯	◯	◯

3.10. Regarding the relevance of the "Interaction" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Interaction:	Includes: interaction style (standard, active, pervasive), presence of multimodality (refers to the existence of an interface multimodal, that is, an interface that allows the possibility of having more than one input modality that can be selected, according to the patient abilities), and interaction modalities.

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Interaction	◯	◯	◯	◯	◯
- Interaction Style	◯	◯	◯	◯	◯
-- Standard (Mouse, Keyboard)	◯	◯	◯	◯	◯
-- Active	◯	◯	◯	◯	◯
-- Pervasive	◯	◯	◯	◯	◯
- Multimodality	◯	◯	◯	◯	◯
-- Yes	◯	◯	◯	◯	◯
-- No	◯	◯	◯	◯	◯
- Interaction Modalities	◯	◯	◯	◯	◯
-- Keyboard	◯	◯	◯	◯	◯
-- Mouse	◯	◯	◯	◯	◯
--Voice/Speech	◯	◯	◯	◯	◯

-- Touch/Multitouch	◯	◯	◯	◯	◯
-- TUI	◯	◯	◯	◯	◯
-- Eye gaze Tracking	◯	◯	◯	◯	◯
-- Haptics	◯	◯	◯	◯	◯
-- Facial Expression Recognition	◯	◯	◯	◯	◯
-- Biofeedback	◯	◯	◯	◯	◯
--- EMG	◯	◯	◯	◯	◯
--- Termal Biofeedback	◯	◯	◯	◯	◯
---EEEG	◯	◯	◯	◯	◯
---- BCI	◯	◯	◯	◯	◯
-- Motion Capture	◯	◯	◯	◯	◯
--- Non-optical - Inertial based	◯	◯	◯	◯	◯
---- Nintendo Wii	◯	◯	◯	◯	◯
---- Wii Balance Board	◯	◯	◯	◯	◯
---- Data Gloves	◯	◯	◯	◯	◯
---- Mobile Phones	◯	◯	◯	◯	◯
--- Optical	◯	◯	◯	◯	◯
---- With Markers	◯	◯	◯	◯	◯
----- Sony Move	◯	◯	◯	◯	◯
----- Sony EyeToy	◯	◯	◯	◯	◯
---- Without Markers	◯	◯	◯	◯	◯
----- Kinect	◯	◯	◯	◯	◯
----- Leap Motion	◯	◯	◯	◯	◯
----- Xtion	◯	◯	◯	◯	◯

3.11. Regarding the relevance of the "Game Platform" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Game Platform:	Can refer the Hardware architecture (the physical components of the game system) and the Game Deployment (environment on which the game runs: Web, Local or a combination of the two previous values).

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Game Platform	◯	◯	◯	◯	◯
- Hardware	◯	◯	◯	◯	◯
-- PC	◯	◯	◯	◯	◯
-- Smartphone/Tablet	◯	◯	◯	◯	◯
-- Console	◯	◯	◯	◯	◯
- Deployment	◯	◯	◯	◯	◯

-- Web	◯	◯	◯	◯	◯
-- Local	◯	◯	◯	◯	◯
-- Mixed	◯	◯	◯	◯	◯

3.12. Regarding the relevance of the "Clinical Evaluation" dimension and of its sub-dimensions in the taxonomy, choose the option you consider most appropriate:

Dimension / Criterion	Description
Clinical Evaluation:	Includes the user tests done with the game system. For each study it is important the study aim, the study type (randomized control trial, pilot study, case control study, review, usability study, etc.), the instruments of measurement used and the number of participants.

	Not Relevant	Slightly Relevant	Relevant	Fairly Relevant	Very Relevant
Clinical Evaluation	◯	◯	◯	◯	◯
- Study Aim	◯	◯	◯	◯	◯
- Study Type	◯	◯	◯	◯	◯
- Instruments	◯	◯	◯	◯	◯
- Sample Size	◯	◯	◯	◯	◯

3.13. What other dimensions would you like to see included in the taxonomy?

____

____

3.14. Do you think that the subdivisions /subtypes proposed for any of the dimensions should be changed? In that case, what new subdivisions / subtypes do you find useful to define for that dimensions? Indicate them here and justify.

____

____

3.15. Regarding the names considered for the dimensions, would you change the names of the dimensions? If so, suggest / propose the new names here:

____

____

4. Taxonomy - Global evaluation

4.1. Regarding the proposed taxonomy:

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
I found it interesting.	○	○	○	○	○
I found it useful.	○	○	○	○	○
I found it complete.	○	○	○	○	○
I found it easy to use.	○	○	○	○	○
I found it easy to extend.	○	○	○	○	○

4.2. I could use the proposed taxonomy:

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
In full, to classify my game.	○	○	○	○	○
Partially, to classify my game.	○	○	○	○	○
I would use it, but in a different way.	○	○	○	○	○
I would not use this taxonomy to classify my game.	○	○	○	○	○

4.3. If you answered in the previous question that you would not use the proposed taxonomy, or that you would use it in a different way, please provide here a justification for your answer.

____

____

4.4. Would you like to receive the results of this survey?

Yes ○

No ○

Annex B – Rehab+ Questionnaire - Usability, Motivation and Experience (study with Healthy users)

Rehab+ - Questionário – Usabilidade, Motivação e Experiência

Bem-vindo ao Questionário de Usabilidade, Motivação e Experiência sobre a plataforma Rehab+. No âmbito do trabalho de doutoramento, "Serious Games for Health Rehabilitation", realizado na Faculdade de Engenharia da Universidade do Porto (FEUP), sob a orientação do Professor Doutor Luís Paulo Reis e do Professor Doutor Pedro Miguel Moreira, pretende-se testar a Plataforma Rehab+, composta por um conjunto de jogos que visam estimular e/ou reabilitar capacidades cognitivas.

Este questionário visa recolher as opiniões dos utilizadores escolhidos para testar esta plataforma, de forma a avaliar a motivação, usabilidade, e a experiência de utilização das atividades que a compõem.

O questionário tem uma duração prevista de 10 minutos.

Agradecemos a sua participação.

Paula Alexandra Carvalho de Sousa Rego
Programa Doutoral em Engenharia Informática, FEUP

ID:

Nome Completo:

1.1. Género
- ❍ Masculino (1)
- ❍ Feminino (2)

1.2 Idade

1.3 Apresenta alguma dificuldade motora?
- ❍ Sim. Qual(ais)? (1) ____________________
- ❍ Não (2)

1.4 Indique o seu caso:
- ❍ Destro (1)
- ❍ Esquerdino (2)

1.5 Tem daltonismo?

- Sim (1)
- Não (2)

1.6 Assinale o seu nível de escolaridade (ou que frequenta):

- Não sei (1)
- Não sei ler nem escrever (2)
- 1º Ciclo (1º - 4º anos) (3)
- 2º Ciclo (5º - 6º anos) (4)
- 3º Ciclo (7º - 9º anos) (5)
- Secundário (4)
- Bacharelato (5)
- Licenciatura (6)
- Mestrado (7)
- Doutoramento (8)

1.7 Indique o seu ramo de estudo/profissão.

1.8 Utiliza regularmente o computador?

- Nunca (1)
- Raramente (uma vez por mês) (2)
- Às vezes (1 vez por semana) (3)
- Muitas vezes (todos os dias, 1 hora ou menos) (4)
- Sempre (todos os dias, mais de 1 hora) (5)

1.9 Costuma jogar regularmente jogos de computador?

- Nunca (1)
- Raramente (uma vez por mês) (2)
- Às vezes (1 vez por semana) (3)
- Muitas vezes (todos os dias, 1 hora ou menos) (4)
- Sempre (todos os dias, mais de 1 hora) (5)

Nas próximas questões assinale a opção que melhor caraterize a sua experiência de jogo.

2.1. Gostei de jogar o jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração MP	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.2. Fiquei frustrado no final do jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo Colaborativo	❍	❍	❍	❍	❍	❍	❍
Ordenação MP	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap)	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.3. Fiquei frustrado enquanto jogava o jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo Colaborativo	❍	❍	❍	❍	❍	❍	❍
Ordenação MP	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.4. Eu gostei do jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação (2)	❍	❍	❍	❍	❍	❍	❍
Cálculo (3)	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice (4)	❍	❍	❍	❍	❍	❍	❍
Cálculo Colaborativo (6)	❍	❍	❍	❍	❍	❍	❍
Ordenação MP (7)	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap (8)	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.5. Eu jogaria este jogo novamente

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo Colaborativo	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.6. Eu senti-me em controlo do jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.7. Os comandos responderam tal como eu esperava

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.8. Eu lembro-me do que os comandos do jogo faziam

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.9. Enquanto eu estava a jogar, consegui ver no monitor tudo o que precisava

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.10. A opinião que eu tinha do jogo estragou a minha experiência de jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.11. Eu sabia o que tinha de fazer para ganhar o jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.12. Houve alturas em que eu não estava a fazer nada no jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.13. Eu gostei da forma como o jogo parecia, do seu design

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.14. Os gráficos do jogo eram simples

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.15. Não gosto deste tipo de jogos

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.16. Gosto de passar muito tempo a jogar este tipo de jogos

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.17. Fiquei aborrecido enquanto jogava este jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.18. Normalmente não escolho este tipo de jogos

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.19. Eu não tinha uma estratégia para ganhar o jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.20. O jogo fez-me sentir constantemente motivado para continuar a jogar

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.21. Eu senti que o que estava a acontecer no jogo era fruto das minhas ações

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.22. Desafiei-me a mim próprio, mesmo se o jogo não o requeresse

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.23. Eu joguei com as minhas próprias regras

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.24. Senti-me culpado pelas ações no jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.25. Eu sabia como manipular o jogo para seguir em frente

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.26. Os gráficos eram apropriados para o tipo de jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.27. Os gráficos do jogo relacionavam-se com o seu cenário

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.28. O jogo era injusto

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.29. Percebi as regras do jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação (2)	❍	❍	❍	❍	❍	❍	❍
Cálculo (3)	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice (4)	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP (6)	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer (7)	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap (8)	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.30. O jogo era desafiador

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.31. O jogo era difícil

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.32. O cenário do jogo era interessante

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.33. Não gostei do cenário do jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

2.34. Eu sabia todas as ações que podia executar no jogo

	Discordo totalmente (1)	Discordo em grande parte (2)	Discordo em parte (3)	Nem discordo nem concordo (4)	Concordo em parte (5)	Concordo em grande parte (6)	Concordo totalmente (7)
Ordenação	❍	❍	❍	❍	❍	❍	❍
Cálculo	❍	❍	❍	❍	❍	❍	❍
Cálculo Voice	❍	❍	❍	❍	❍	❍	❍
Cálculo COOP	❍	❍	❍	❍	❍	❍	❍
Ordenação Multiplayer	❍	❍	❍	❍	❍	❍	❍
Ordenação Handicap	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração	❍	❍	❍	❍	❍	❍	❍
Atenção e Concentração Colaborativo	❍	❍	❍	❍	❍	❍	❍
Memória Palavras	❍	❍	❍	❍	❍	❍	❍
Memória Palavras MP	❍	❍	❍	❍	❍	❍	❍

Nas próximas questões assinale a opção que melhor caraterize a sua experiência de utilização da plataforma Rehab+.

	Discordo totalmente (1)	Discordo parcialmente (2)	Indiferente (3)	Concordo parcialmente (4)	Concordo totalmente (5)
3.1. Gostaria de utilizar este sistema frequentemente (1)	❍	❍	❍	❍	❍
3.2. Considero o sistema desnecessariamente complexo (2)	❍	❍	❍	❍	❍
3.3. O sistema é fácil de utilizar (3)	❍	❍	❍	❍	❍
3.4. Considero que poderia precisar de apoio de alguém especializado para poder utilizar este sistema (4)	❍	❍	❍	❍	❍
3.5. As várias funções do sistema foram bem integradas (5)	❍	❍	❍	❍	❍
3.6. Considero haver demasiada inconsistência neste sistema (6)	❍	❍	❍	❍	❍
3.7. Julgo que a maioria das pessoas iria aprender a utilizar este sistema muito rapidamente (7)	❍	❍	❍	❍	❍
3.8. Considero a utilização do sistema muito incómoda (8)	❍	❍	❍	❍	❍
3.9. Senti-me muito confiante a utilizar o sistema (9)	❍	❍	❍	❍	❍
3.10. Considero que precisaria de aprender muitas coisas antes de poder utilizar este sistema (10)	❍	❍	❍	❍	❍

Nas próximas questões assinale a opção que melhor caraterize a sua experiência em relação a toda esta atividade.

	Discordo totalmente (1)	Discordo parcialmente (2)	Indiferente (3)	Concordo parcialmente (4)	Concordo totalmente (5)
4.1. Gostei muito de participar nesta atividade (1)	❍	❍	❍	❍	❍
4.2. Esta atividade foi divertida (2)	❍	❍	❍	❍	❍
4.3. Esta atividade foi aborrecida (3)	❍	❍	❍	❍	❍
4.4. Esta atividade não prendeu a minha atenção (4)	❍	❍	❍	❍	❍
4.5. Descreveria esta atividade como muito interessante (5)	❍	❍	❍	❍	❍
4.6. Esta atividade foi bastante satisfatória (6)	❍	❍	❍	❍	❍
4.7. Enquanto estava a praticar esta atividade, estava a pensar em como estava a gostar dela (7)	❍	❍	❍	❍	❍

5.1 Os jogos apresentados foram divididos em duas categorias, Single Player e Multiplayer.

	Single Player (1)	MuliPlayer (2)	Indiferente (3)
Qual das modalidades prefere? (1)	❍	❍	❍
Qual das modalidades considerou mais desafiadora? (2)	❍	❍	❍
Qual das modalidades prefere em relação ao jogo ordenação? (3)	❍	❍	❍

5.2 A versão multiplayer do jogo ordenação foi apresentada em duas vertentes, Ordenação Multiplayer e Ordenação Handicap.

	MultiPlayer (1)	Handicap (2)	Não notei diferença nenhuma (3)
De qual gostou mais? (1)	❍	❍	❍
Qual considerou mais desafiante? (2)	❍	❍	❍

5.3 O jogo de Cálculo Mental utilizou duas formas de interação diferentes: rato e voz.

	Rato (1)	Voz (2)	Não notei diferença nenhuma (3)
De qual gostou mais? (1)	❍	❍	❍
Qual considerou mais desafiante? (2)	❍	❍	❍
Que tipo de comandos considerou mais intuitivos? (3)	❍	❍	❍
Qual o mais divertido? (4)	❍	❍	❍
Com qual foi mais difícil de interagir? (5)	❍	❍	❍

5.4 Os jogos Multiplayer apresentados seguiram duas abordagens diferente, a competição (Ordenação MP, Atenção MP, Memória Palavras MP) onde enfrentou um adversário, e a colaboração (Cálculo Colaborativo, Atenção Colaborativo), onde ambos os jogadores formaram equipa. Em relação a estas duas abordagens marque as respostas que melhor descrevem a sua opinião.

	Competição (1)	Colaboração (2)	Igual (3)
Qual gostou mais? (1)	❍	❍	❍
Qual considerou mais desafiante? (2)	❍	❍	❍
Em qual se divertiu mais? (3)	❍	❍	❍
Qual considera que criou maior interação entre os jogadores? (4)	❍	❍	❍

5.5 Se necessitasse de participar numa atividade de estímulo cognitivo, julga que se sentiria mais motivado com recurso a:

- ❑ Exercícios tradicionais (utilização de papel, caneta, jogos de tabuleiro, etc.) (1)
- ❑ Jogos deste tipo que utilizam um computador (2)
- ❑ Praticar somente nas horas e locais destinados à terapia (3)
- ❑ Praticar em casa ou noutro local à sua escolha, à hora que preferisse (4)
- ❑ Praticar sozinho (5)
- ❑ Praticar em grupo (6)

6. Por favor, indique os seus comentários/sugestões.

Annex C – Rehab+ - Informed consent form (study with Elderly users)

Informed Consent

Declaração de consentimento informado

Conforme a lei 67/98 de 26 de outubro e a "Declaração de Helsínquia" da Associação Médica Mundial
(Helsínquia 1964; Tóquio 1975; Veneza 1983; Hong Kong 1989; Somerset West 1996, Edimburgo 2000;
Washington 2002, Tóquio 2004, Seul 2008, Fortaleza
2013)

Designação do Estudo: Serious Games for Health Rehabilitation

Eu, ____ abaixo assinado (ou Eu, ____(nome completo do representante legal do indivíduo participante do estudo), na qualidade de representante legal de ____ (nome completo do indivíduo participante do estudo)), fui informado de que o Estudo de Investigação acima mencionado se destina a obter dados sobre a satisfação e o desempenho na utilização da Plataforma Rehab+ composta por um conjunto de jogos com o propósito de estimular e/ou reabilitar as funções cognitivas. Os jogos são jogados usando o rato e comandos de voz, tendo-me sido explicado em que consistem e quais os possíveis efeitos.

Sei que neste estudo está previsto o preenchimento de um questionário após a utilização da plataforma. Foi-me garantido que todos os dados relativos à identificação dos participantes neste estudo são confidenciais e que será mantido o anonimato.

Sei que posso recusar-me a participar ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto. (ou Sei que posso recusar-me a autorizar a participação ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto).

Compreendi a informação que me foi dada, tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas.

Aceito participar de livre vontade no estudo acima mencionado (ou Autorizo de livre vontade a participação daquele que legalmente represento no estudo acima mencionado).

Também autorizo a divulgação dos resultados obtidos no meio científico, garantindo o anonimato.

Data ___/___/_____

Assinatura ______________________________

Annex D – Rehab+ Questionnaire A – Pre-Selection (study with Elderly users)

Nome do Participante:

ID:

Rehab+ - Questionário A - Pré-seleção

No âmbito do trabalho de doutoramento, "Serious Games for Health Rehabilitation", realizado na Faculdade de Engenharia da Universidade do Porto (FEUP), sob a orientação do Professor Doutor Luís Paulo Reis e do Professor Doutor Pedro Miguel Moreira, pretende-se testar a plataforma Rehab+, composta por um conjunto de jogos que visam estimular e/ou reabilitar capacidades cognitivas.

Este questionário visa recolher dados sociodemográficos dos utilizadores escolhidos para testar esta plataforma. Os dados fornecidos serão tratados de forma agregada, bem como será mantida a confidencialidade.

Agradecemos a disponibilidade e colaboração.

Paula Alexandra Carvalho de Sousa Rego
Programa Doutoral em Engenharia Informática, FEUP

Data: ___ / ___ / ______
ID:________

Nome Completo:

1.1. Género

❍ Masculino (1)
❍ Feminino (2)

1.2 Idade

1.3 Indique o seu caso:

❍ Destro (1)
❍ Esquerdino (2)

1.4 Tem daltonismo?

- ❍ Sim (1)
- ❍ Não (2)

1.5 Apresenta alguma dificuldade motora?

- ❍ Sim. Qual(ais)? (1) ____________________
- ❍ Não (2)

1.6 Apresenta alguma dificuldade cognitiva?

- ❍ Sim. Qual(ais)? (1) ____________________
- ❍ Não (2)

1.7 Apresenta alguma dificuldade de visão?

- ❍ Sim. Qual(ais)? (1) ____________________
- ❍ Não (2)

1.8 Apresenta alguma dificuldade de audição?

- ❍ Sim. Qual(ais)? (1) ____________________
- ❍ Não (2)

1.9 Outras dificuldades:

1.10 Assinale o seu nível de escolaridade:

- ❍ Não sei (1)
- ❍ Não sei ler nem escrever (2)
- ❍ 1º Ciclo (1º - 4º anos) (3)
- ❍ 2º Ciclo (5º - 6º anos) (4)
- ❍ 3º Ciclo (7º - 9º anos) (5)
- ❍ Secundário (6)
- ❍ Bacharelato (7)
- ❍ Licenciatura (8)
- ❍ Mestrado (9)
- ❍ Doutoramento (10)

1.11 Profissão:

1.12 Profissão anterior:

- ❍ Quadros superiores da administração pública, dirigentes e quadros superiores de empresa (1)
- ❍ Profissões intelectuais e científicas (2)
- ❍ Técnicos e profissionais de nível intermédio (3)
- ❍ Pessoal administrativo e similares (4)
- ❍ Pessoal dos serviços e vendedores (5)
- ❍ Agricultores e trabalhadores qualificados da agricultura e pescas (6)
- ❍ Operários, artífices e trabalhadores similares (7)
- ❍ Operários de instalações e máquinas e trabalhadores da montagem (8)
- ❍ Profissões não qualificadas (9)
- ❍ Doméstico(a) (10)
- ❍ Forças armadas (11)
- ❍ Não se aplica (12)

1.13 Utiliza regularmente o computador?

- ❍ Nunca (1)
- ❍ Raramente (uma vez por mês) (2)
- ❍ Às vezes (1 vez por semana) (3)
- ❍ Muitas vezes (todos os dias, 1 hora ou menos) (4)
- ❍ Sempre (todos os dias, mais de 1 hora) (5)

1.14 Costuma jogar regularmente jogos de computador?

- ❍ Nunca (1)
- ❍ Raramente (uma vez por mês) (2)
- ❍ Às vezes (1 vez por semana) (3)
- ❍ Muitas vezes (todos os dias, 1 hora ou menos) (4)
- ❍ Sempre (todos os dias, mais de 1 hora) (5)

Annex E – Rehab+ Questionnaire B – Subjective Experience with the Game (Enjoyment, Perceived competence, effort/importance, and pressure/tension) (study with Elderly users)

1. While playing the game, I was thinking about how much I enjoyed it.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

2. I put a lot of effort into the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

3. I couldn't play the game very well.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

4. I did not feel nervous at all during the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

5. I think I am pretty good at the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

6. I found the game very interesting.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

7. I tried as hard as I could during the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

8. I felt very tense during the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

9. It was important for me to do well at the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

10. I think I did pretty well at the game, compared to other players.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

11. The game was fun to play.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

12. I was very relaxed during the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

13. I didn't put much energy into the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

14. I'm satisfied with my performance in the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

15. I enjoyed the game very much.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

16. I didn't try very hard to do well at the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

17. I was frightened during the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

18. After playing the game for a while, I felt pretty competent.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

19. I felt pressured during the game.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

20. I think the game was boring.

	not at all true						very true
Sorting Single player	1	2	3	4	5	6	7
Sorting Competitive	1	2	3	4	5	6	7
Sorting Competitive with Handicap	1	2	3	4	5	6	7

Annex F – Rehab+ Questionnaire C – Post-Experiment (study with Elderly users)

Post-Experiment Questionnaire/ Questionário Final

ID: _________

Nas próximas assinale a opção que melhor se adequa.

1.1 Os jogos apresentados foram divididos em duas categorias, Single Player e Multiplayer.

	Single Player (1)	MuliPlayer (2)	Indiferente (3)
Qual das modalidades prefere? (1)	❍	❍	❍
Qual das modalidades considerou mais desafiadora? (2)	❍	❍	❍
Qual das modalidades prefere em relação ao jogo ordenação? (3)	❍	❍	❍

2.2 A versão multiplayer do jogo ordenação foi apresentada em duas vertentes, Ordenação Multiplayer e Ordenação Handicap.

	MultiPlayer (1)	Handicap (2)	Não notei diferença nenhuma (3)
De qual gostou mais? (1)	❍	❍	❍
Qual considerou mais desafiante? (2)	❍	❍	❍

2.3 O jogo de Cálculo Mental utilizou duas formas de interação diferentes: rato e voz.

	Rato (1)	Voz (2)	Não notei diferença nenhuma (3)
De qual gostou mais? (1)	❍	❍	❍
Qual considerou mais desafiante? (2)	❍	❍	❍
Que tipo de comandos considerou mais intuitivos? (3)	❍	❍	❍
Qual o mais divertido? (4)	❍	❍	❍
Com qual foi mais difícil de interagir? (5)	❍	❍	❍

2.4 Os jogos Multiplayer apresentados seguiram duas abordagens diferente, a competição (Ordenação MP, Atenção MP, Memória Palavras MP) onde enfrentou um adversário, e a colaboração (Cálculo Colaborativo, Atenção Colaborativo), onde ambos os jogadores formaram equipa. Em relação a estas duas abordagens marque as respostas que melhor descrevem a sua opinião.

	Competição (1)	Colaboração (2)	Igual (3)
Qual gostou mais? (1)	❍	❍	❍
Qual considerou mais desafiante? (2)	❍	❍	❍
Em qual se divertiu mais? (3)	❍	❍	❍
Qual considera que criou maior interação entre os jogadores? (4)	❍	❍	❍

2.5 Comparando as diferentes versões de cada jogo, escolha a que melhor descreve a sua opinião.

2.5. 1 Para cada um dos jogos, qual foi a sua vertente favorita?

	Single Player usando Rato (1)	Single Player usando comandos de voz (2)	Competição (3)	Colaboração (4)	Competição com Handicap (5)
Ordenação(1)	❍		❍		❍
Cálculo (2)	❍	❍		❍	
Atenção - Concentração (3)	❍		❍	❍	
Memória de Palavras (4)	❍		❍		

Porquê? (Justifique)

Ordenação: ____

Cálculo: ____

Atenção-Concentração: ____

Memória de Palavras:____

2.5. 2 Para cada um dos jogos, qual foi a vertente de que menos gostou?

	Single Player usando Rato (1)	Single Player usando comandos de voz (2)	Competição (3)	Colaboração (4)	Competição com Handicap (5)
Ordenação(1)	❍		❍		❍
Cálculo (2)	❍	❍		❍	
Atenção - Concentração (3)	❍		❍	❍	
Memória de Palavras (4)	❍		❍		

Porquê? (Justifique)

Ordenação: ____

Cálculo: ____

Atenção-Concentração: ____

Memória de Palavras:___________________________________

2.5. 3 Para cada um dos jogos, qual foi a vertente na qual se esforçou mais?

	Single Player usando Rato (1)	Single Player usando comandos de voz (2)	Competição (3)	Colaboração (4)	Competição com Handicap (5)
Ordenação(1)	❍		❍		❍
Cálculo (2)	❍	❍		❍	
Atenção - Concentração (3)	❍		❍	❍	
Memória de Palavras (4)	❍		❍		

2.5. 4 Para cada um dos jogos, qual foi a vertente na qual se esforçou menos?

	Single Player usando Rato (1)	Single Player usando comandos de voz (2)	Competição (3)	Colaboração (4)	Competição com Handicap (5)
Ordenação(1)	❍		❍		❍
Cálculo (2)	❍	❍		❍	
Atenção - Concentração (3)	❍		❍	❍	
Memória de Palavras (4)	❍		❍		

2.5. 5 Para cada um dos jogos, qual foi a vertente na qual se sentiu mais competente?

	Single Player usando Rato (1)	Single Player usando comandos de voz (2)	Competição (3)	Colaboração (4)	Competição com Handicap (5)
Ordenação(1)	❍		❍		❍
Cálculo (2)	❍	❍		❍	
Atenção - Concentração (3)	❍		❍	❍	
Memória de Palavras (4)	❍		❍		

2.5. 6 Para cada um dos jogos, qual foi a vertente na qual se sentiu menos competente?

	Single Player usando Rato (1)	Single Player usando comandos de voz (2)	Competição (3)	Colaboração (4)	Competição com Handicap (5)
Ordenação(1)	❍		❍		❍
Cálculo (2)	❍	❍		❍	
Atenção - Concentração (3)	❍		❍	❍	
Memória de Palavras (4)	❍		❍		

2.5. 7 Para cada um dos jogos, qual foi a vertente mais stressante?

	Single Player usando Rato (1)	Single Player usando comandos de voz (2)	Competição (3)	Colaboração (4)	Competição com Handicap (5)
Ordenação(1)	❍		❍		❍
Cálculo (2)	❍	❍		❍	
Atenção - Concentração (3)	❍		❍	❍	
Memória de Palavras (4)	❍		❍		

2.5. 8 Para cada um dos jogos, qual foi a vertente menos stressante?

	Single Player usando Rato (1)	Single Player usando comandos de voz (2)	Competição (3)	Colaboração (4)	Competição com Handicap (5)
Ordenação(1)	❍		❍		❍
Cálculo (2)	❍	❍		❍	
Atenção - Concentração (3)	❍		❍	❍	
Memória de Palavras (4)	❍		❍		

2.6 Se necessitasse de participar numa atividade de estímulo cognitivo, julga que se sentiria mais motivado com recurso a:

- ❑ Exercícios tradicionais (utilização de papel, caneta, jogos de tabuleiro, etc.) (1)
- ❑ Jogos deste tipo que utilizam um computador (2)
- ❑ Praticar somente nas horas e locais destinados à terapia (3)
- ❑ Praticar em casa ou noutro local à sua escolha, à hora que preferisse (4)
- ❑ Praticar sozinho (5)
- ❑ Praticar em grupo (6)

6. Por favor, indique os seus comentários/sugestões.

Annex G - Work Plan

During this research work several tasks will take place. The tasks are the following:

- T1: Initial Literature Review
- T2: Identification of Relevant Game Features
- T3: Identification of Relevant NUI and Multi-modality
- T4: Prototype Design and Experiments
- T5: Serious Game Design and Implementation
- T6: Experiments and System Validation
- T7: Thesis Writing

The following subsection detail each of these tasks and the thesis work plan schedule.

8.4 Curricular Component

The curricular component respects the first year of the Doctoral Program in Informatics Engineering, corresponding to 60 European Credit Transfer and Accumulation System (ECTS). This component was comprised of the following four courses: Methodologies for Scientific Research, Interaction and Visual Simulation Environments, Multi-agent Systems, Research Planning and Advanced Methods of Modelling and Simulation.

During the curricular component of the Doctoral Program in Informatics Engineering there is some work that has been developed. In this section we present that work.

To have knowledge of the applications of serious games existing in rehabilitation area, it was made a literature review. From this review, we find a set of criteria that we consider relevant to compare and classify existing systems. This part of the work has already been published in [90].

From this comparison and classification, we found that game features as collaboration and competitiveness were very poor explored in the reviewed games and can contribute to increase motivation and engagement in the games. Another aspect is that in most of the works the way that patients interact with the system is not very well adapted to their physical or motor abilities. Additionally, almost all the works reported were only prototypes and tested with a small number of patients, which is insufficient to extract reliable conclusions from these user studies. All these aspects we consider as important opportunities for our future research.

8.5 T1: Initial Literature Review

Some of the literature review was already done, as presented in Chapter 2. Throughout this task, the state-of-the-art will be further analyzed with emphasis on research work on the fields of rehabilitation, Serious Games, Serious Games for rehabilitation and game design methodologies. As the main outcome of this research task we intend to have a comprehensive report of the underlying concepts, knowledge, methodologies and systems described in the literature. We also intend to be able to identify and compare the proposed approaches, and to point out advantages and weaknesses of the described works. This outcome will serve as a foundation to the next tasks as it will enable us to identify the innovative aspects of our proposals and compare to other works.

Additionally, another aspect in which we will focus our revision of the literature is on interaction technology, mainly in the use of natural user interfaces. The literature review made until now of natural user interfaces was described in Chapter 2, section 2.4.

8.6 T2: Identification of Relevant Game Features

As, to the best of our knowledge, the existing systems can be very different, we intend to develop and propose a classification schema that leads into a taxonomy, in order to assist the comparison of such systems in respect to the more relevant features identified. Based on that classification, existing games could be modified in order to satisfy a large number of the classification criteria and become more functional tools for the rehabilitation therapy.

From our preliminary research [90, 282] we have found some important criteria for serious games classification, such as: Application area, Interaction Technology, Game interface, Game Genre, Adaptability, Performance Feedback, Progress monitoring and Game portability. These criteria gave us a more clear understanding what is being done in this area. We have identified some opportunities, as for instance: the inclusion of a social dimension into the games; the use of competitive and collaborative settings; and also the integration of surrogate players (e.g. by means of software agents), that is less explored in the reviewed literature and constitute opportunities to further research. It is expected that collaboration and competition add new dimensions to game play that will allow the patients to enjoy the interaction and found the motivation and encouragement from others playing the same game. We have also noticed some limitations that will serve as starting points of further research.

8.7 T3: Identification of Relevant NUI and Multi-modality

In what concerns to interaction technology we want to identify how natural user interfaces can benefit the design of games that are adapted to different users, with varied capabilities and handicaps, enabling them to choose alternated or combined modalities of input, according to their capabilities.

In this task we aim at further developing the proposed classification in order to build a complete and unified classification system that may help in identifying the main features to be included in the serious games to be developed. As another outcome, it is expected to produce game design guidelines, as well as, specifications of software tools that will enable the inclusion of such features.

8.8 T4: Prototype Design and Implementation

This task aims to design and implement a prototype game incorporating some identified relevant features, such as multimodal interaction. This task also comprehends a preliminary users study. The prototype usability test results will be used to define and test an initial architecture for our system. With this prototype it is expected that potential problems can be identified in an earlier stage as also as a source of new knowledge about the overall system functionality. This will enable the definition of a more robust and sustainable architecture for our system.

This task has been already developed. The prototype description and achieved results and conclusions are presented in section 3.4.

8.9 T5: Serious Game Design and Implementation

One of the main goals of this task is to propose an architecture that enables to include the set of features we identified as relevant for SGHR. Based on the architecture proposed we aim to develop a set of games that will enable to test and validate the identified relevant features. These implementations will mainly serve to conduct experiences in order to validate our proposals.

Therefore, we would have to study how the effectiveness of rehabilitation computer games can be increased by incorporating these new features, e.g. the social dimension (collaboration or competition), in particular when patients are at different stages of their rehabilitation process or have different handicaps. Early user testing (direct observation, enquiries, etc.) is also planned in order to provide us with useful information concerning to usability and motivation. This task is concerned with the real project and implementation of the serious games including the identified features.

8.10 T6: Experiments and System Validation

After having the serious games application designed and fully implemented, the system has to be tested and validated with a significant sample of patients. The patients will be subjected to a specific rehabilitation plan using the developed serious games. These patients will be required to perform a set of tasks during their rehabilitation period. Several observations acquired during their rehabilitation will be analyzed. In order to perform the needed experiments, a partnership with IIFR - Instituto de Investigação e Formação Rodoviária was already established. This Institute has access to a significant sample of patients in rehabilitation from severe traffic accidents. As the main outcome of this task it is expected a set of designed experiments and their corresponding results that can be used to assess, validate and compare our proposals.

8.11 T7: Thesis Writing

During all the project timeline it is our intention to disseminate and discuss, as earlier as possible, our findings, proposals and results within the scientific community. This will be accomplished by means of scientific communications, conference papers and journal articles.

The final thesis redaction will be made in the last six months. The papers and articles that were written before will be incorporated into the final thesis (fully or partially). This procedure is expected to make this thesis writing task shorter in duration.

8.12 Schedule

This research project is divided in seven main phases, as can be seen in the tabular graph presented in Figure 119- curricular component and initial literature review, identification of relevant game features, identification of relevant NUI and Multi-modality, serious game design and implementation, experiments and system validation, and finally, the thesis writing.

In the graph are also illustrated the contributions from possible paper publications.

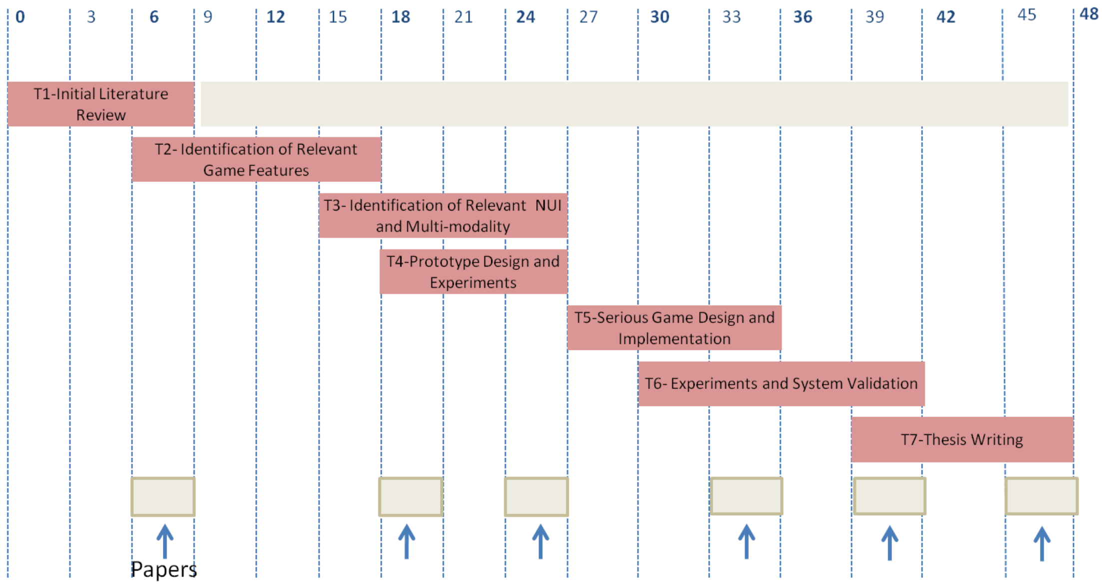

Figure 119 - Schedule of the thesis proposal.

Although the first phase of the plan pertains to the study of the state of the art, it also encompasses the curricular component integrated in the doctoral program.